Non-Uniform, Curved, Expanded and Inclined Diffraction Pattern of 1D-Grating Experiments ---Rotating Grating Around Three Axes

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Non-Uniform, Curved, Expanded and Inclined Diffraction Pattern of 1D-Grating Experiments ---Rotating Grating Around Three Axes

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Abstract The orientation-dependence of the diffraction patterns of the 1D-grating experiments have been studied experimentally and theoretically. However, the experiments were limited to certain orientations, namely rotate the grating around two axes. We introduce the 3-axis-rotation apparatus, which can rotate the 1D-grating, CW and CCW respectively, by 0° - 360° around three axes independently and sequentially. By this apparatus, the orientation-dependence of the patterns of the 1D-grating is systematically studied. The experiments show the novel phenomena: when rotating the grating around three axes, not only the patterns are curved, expanded and inclined, but also the spacings between the adjacent orders of the patterns are non-uniform.

More specifically, the spacings increase gradually from one end of the pattern to the other end of the pattern. The above observed phenomena provide the comprehensive information to theoretical study of the grating experiments further. We suggest that the complete mathematical model should contain three rotation angles as parameters. Furthermore, the phenomena have potential applications.

Keywords: 1D-grating experiment, diffraction pattern, non-uniform diffraction pattern, curved diffraction pattern, expanded diffraction pattern, inclined diffraction pattern, light bending

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1. Introduction

The orientation-dependence of the conical diffraction patterns (hereafter denoted as “pattern”) of the 1D-grating experiments have been predicted theoretically [1]. Based on the different theoretical models, the conical patterns are studied experimentally further [2,3]. However, in the above experiments, the phenomena of the expanded pattern, the curved-expanded pattern and the curved-expanded-inclined pattern were not revealed. Moreover, the studies of the orientation-dependence were limited to the certain orientations, namely limited to rotate the grating around two axes and, thus were not complete.

The interference patterns of the 1D-double slit and 2D-cross-double slit experiments have been studied experimentally and theoretically [4,5]. The novel phenomena of the orientation-dependence, i.e., the patterns not only can be curved, but also can be expanded and inclined simultaneously and continuously, have been reported [6,7]. It is shown that the phenomena are universal, namely, the curved pattern, the expanded pattern, the curved-expanded pattern and the curved-expanded-inclined pattern emerge in the single slit, double slit, cross-double slit, triple slit and 1D-grating experiments. Theoretical analyses were presented: (1) Right-hand rule and Left-hand rule for determining the direction of the patterns curve toward are proposed; (2) the mathematical formulars for describing the expansion and the inclination of the patterns are derived. Also, the particle nature of the light in the double slit/cross-double slit experiments has been shown [5]. However, in the above experiments, the

study of the orientation-dependence is limited to rotate the apparatuses around two axes and thus, are not complete.

Recently, the orientation-dependence of the interference patterns of the 1D-double slit/2D-cross-double slit experiments has been extended to the 1D-grating and 2D-cross-grating experiments [6-8]. The phenomena of the simultaneously curved-expanded patterns emerged in the 2D-cross-grating experiments, while the simultaneously curved-expanded-inclined patterns emerged in the tilt-2D-cross-grating experiments. The shapes of patterns are attributing to the different orientations of the 2D-cross-grating and, thus, are conveniently created and controlled. The new phenomena show that the characteristics of the patterns depend on the orientations of the grating. However, the study only covers the orientations by rotating the grating around two axes.

To study the orientation-dependence completely, we introduce: (1) the three-axis-rotation apparatus; and (2) a new coordinate system to describe the new apparatus [9]. By which, the systematic study of the orientation-dependence of the patterns is achieved intuitively. The 1D-gratings are rotated around three axes sequentially and respectively.

New phenomena of the non-uniform spacings between the diffraction orders are observed.

The novel phenomena of the non-uniform, curved, expanded and inclined patterns provide the comprehensive data/information to theoretically study the grating experiments. We suggest that a complete mathematical model should contain three rotation angles as parameters and should be able to describe all phenomena of the orientation-dependence of the patterns consistently.

The concept of the orientation-dependence of the patterns is important for applications.

2. Three-Axis-Rotation Apparatus: Rotating Grating Around Three Axes

2.1. Three-Axis-Rotation Apparatus and Coordinate System

To perform the experiments of studying the orientation-dependence of the patterns, it is practical convenience to keep the laser beam pointing to the same direction and rotate the grating. The laser beam is always perpendicular to the screen. For this aim, we introduce the 3-axis-rotation apparatus.

Three-Axis-Rotation Apparatus (Figure 01b): it can rotate the 1D-grating, clockwise (CW) and counterclockwise (CCW), around three axes to reach desired orientations.

Figure 01. Schematic of Setup of Experiments (a) with 3-axis-rotation apparatus/coordinate (b)

Coordinate system: To describe the rotation of the grating/apparatus, we introduce a special coordinate system X-Y-Z that is attached to the apparatus: the Z axis is attached with the Z-ring and always in the vertical direction, the Y and Z axes are attached with the Y-ring and the X-ring, respectively, and are always perpendicular to each other, while the X and Y axes are always perpendicular to each other.

With the apparatus, we can perform the rotations around the X axis, Y axis and Z axis.

- (1) When the X-ring, taking the grating with it, rotates around the X axis, the rotation angles are either “Clockwise α ” (CW “ α ”) or “Counterclockwise α ” (CCW “ α ”) ($0^\circ \leq \alpha \leq 360^\circ$), the directions of the Y and Z axes do not change; The slits change their direction and form the Y component and the Z component.
- (2) When the Y-ring, taking the X-ring and grating with it, rotates around the Y axis, the rotation angles are either “CW β ” or “CCW β ” ($0^\circ \leq \beta \leq 360^\circ$), the directions of the Z axis and the slits do not change; The X axis changes its direction.
- (3) When the Z-ring, taking the Y-ring, the X-ring and grating with it, rotates around the Z axis, the rotation angles are either “CW γ ” or “CCW γ ” ($0^\circ \leq \gamma \leq 360^\circ$), the direction of the Z axis does not change; The directions of the X axis, the Y axis and the slits change their directions; The slits change their direction and form the X component and the Y component.

The X-ring, Y-ring and Z-ring rotate around the X axis, Y axis and Z axis respectively. With this apparatus, the orientation-dependence of the patterns can be studied thoroughly and conveniently, and novel phenomena are shown.

2.2. Direction of Rotation and Original Orientation

Original orientation: At the original orientation, the slits of the grating are along the Y direction. The laser beam is perpendicular to the Y-Z plane and is along the negative X direction shining on the grating.

The coordinate system is shown in Figure 01. The Z axis keeps the same direction. The laser beam keeps the same direction. To define “CW” and “CCW” rotation, we introduce the right-hand rule.

Direction of Rotation: that the thumb of the right hand is pointed in the direction of the axis, the CCW rotation is given by the curl of the fingers (Figure 02).

Figure 02. Right-hand rule for determining direction of rotation

2.3. Rotating Grating Around Three Axis

To study systematically the orientations-dependence of the diffraction patterns (hereafter denoted as the “patterns”) of the 1D-grating, the effects of the orientations on the patterns need to be considered when the following rotations are performed:

- (A) First, start from the original orientation, then, rotating the grating around one axis.
- (B) Second, start from the original orientation, then, rotating grating around two axes sequentially.
- (C) Third, start from the original orientation, then, rotating the grating around three axes sequentially.

Next, we show the observations of the grating experiments for the orientations of rotating the grating CW and CCW around one, two and three axes.

3. Experiments: Novel Phenomena of Grating Attributing to Rotation Around 3 Axes

3.1. Rotating Grating Around One Axis: Curved Pattern and Expanded Pattern

Let us start from the original orientation (Figure 01c). The slits of the grating are along the Y direction. Then, rotating the 1D-grating around one axis, respectively.

Experiment-1: Rotating Grating Around X axis

Figure 1a shows the pattern due to rotate the grating CW, while Figure 1b shows the pattern due to the CCW rotation. The patterns of the grating have the rotation symmetry when the grating rotates around the X axis and the laser beam is on the normal vector, the X axis.

Figure 1c shows the rotation symmetry of the patterns of the cross-double slit [4].

Figure 1. Rotation symmetry: Grating rotating around X axis: Patterns due to:

(a) rotation CW; (b) rotation CCW; (c) 2D-cross-double slit

Observation: When the light beam normally incidents, the pattern has the rotation-symmetry around the X axis. When the laser beam is oblique incident, the rotation symmetry is no longer valid.

Experiment-2: Rotating Grating Around Y axis

Starting from the original orientation, the pattern is shown in Figure 2a.

Figure 2. Expanded Patterns: Grating rotating around Y Axis CW β (b) and CCW β (c)

Observation: the expanded patterns: the larger the rotation angle, β , the larger the expansion.

When the slits of the grating are along the Y axis, The directions of rotating around Y axis, either CW or CCW, have no effects on the expansion of the patterns.

Mathematic Description:

Figure 03. Incident Lights

In Experiment-2, the incident light beam (Brown colored arrow in Figure 03) is in the X-Z plane with an incident angle β to the X axis, which create the expanded pattern.

The standard grating equation gives

$$\sin\beta_m = \frac{m\lambda}{d} + \sin\beta_i. \quad (1)$$

Where β_m is the diffraction angle, d is the spacing between two adjacent slits. The difference is constant,

$$\sin\beta_{m+1} - \sin\beta_m = \frac{\lambda}{d}. \quad (2)$$

To describe the expanded patterns of Experiment-2, we extend the standard grating equation to:

$$\sin\beta_m = \frac{m\lambda}{d} \sqrt{1 + (\tan\beta_i)^2} + \sin\beta_i. \quad (3)$$

Now the difference is incident-angle-dependent, i.e., the larger the incident angle, the larger the spacing between diffraction orders,

$$\sin\beta_{m+1} - \sin\beta_m = \frac{\lambda}{d} \sqrt{1 + (\tan\beta_i)^2}. \quad (4)$$

The term $(\tan\beta)^2$ shows that the expansions are independent with the directions, either CW β or CCW β , of the grating/ring's rotation.

Note that Equations (1) and (3) describe the patterns created by the oblique incident light beams that are in the X-Z plan (Figure 03) and thus, no pattern is curved.

Experiment-3: Rotating Grating Around Z axis

Starting from the original orientation. Figure 3a shows the pattern of the grating at the original orientation. The patterns have no expansion.

Figure 3. Curved patterns attribute to: CCW rotation (b) and CW rotation (c) of grating

Observation: the curved patterns: the larger the rotation angle, γ , the larger the curvature. The directions of the curves are determined by the direction of the rotations: the CCW rotation makes the

pattern curves towards to the right (Figure 3b), which satisfy the left-hand rule; while the CW rotation makes the pattern curves towards to the left (Figure 3c) [7], which satisfy the right-hand rule.

When the grating rotates around the Z axis, either CW or CCW, the different curved patterns are created as shown in Experiment-3. The incident light beam (Blue colored arrow in Figure 03) is in the X-Y plane with an incident angle γ to the X axis, which created the curved pattern.

Experiment-1, -2 and -3 indicate that the patterns due to the rotations around the different axes are completely different (Table 1). Those differences will guide us to understand the phenomena when the grating rotating around 2 axes and 3 axes.

Table 1. Characteristics of Patterns vs. Rotation Axis

Rotation	Change Direction	Rotation Symmetry	Expand	Curve
Around X Axis	Yes	yes		
Around Y Axis			Yes	
Around Z Axis				Yes

3.2. Rotating Grating Around Two Axes: Curved-Expanded Pattern and

Curved-Expanded-Inclined Pattern

In this section, we perform the following experiments. Note that since the direction of the curved patterns is determined by the direction of the rotation, so in the following experiments, we rotate the grating CW and CCW respectively.

3.2.1. Rotating Grating CW Around X Axis, Then Rotating Grating CW/CCW Around Y Axis

Rotate the grating around the X axis 55° CW, Figure 4a shows its pattern. Then perform the following 2 experiments respectively.

Experiment-4: after rotating the grating around the X axis 55° CW, rotate the grating CW around Y axis by 60° (Figure 4b)

Figure 4. Grating rotates CW around X axis by 55° (a), then rotates grating around Y axis:

Patterns due to CW rotation by 60° (b)

Observation (Figure 4b): the patterns are curved towards the left, expanded and inclined towards the vertical axis.

Experiment-5: after rotating the grating CW around the X axis by 55° , rotating the grating CCW around Y axis by 75° (Figure 5)

Observation (Figure 5b): the patterns are curved towards the right, expanded and inclined towards the vertical axis.

Figure 5. Grating rotates CW around X axis by 55° (a), then rotates grating around Y axis CCW 75° (b)

Mathematic Description: After rotating the grating CW around the X axis by the angle α , the grating is tilt, and the slits of the grating have two components, the Y components and the Z components. If then, rotating the tilt-grating around the Y axis, the Y component create the expanded patterns, while the Z components create the curved patterns. If then, rotating the tilt-grating around the Z axis, the Z component create the expanded patterns, while the Y components create the curved patterns.

When rotating the tilt-grating around the Y axis an angle β_i , the mathematic equation describing the expansion of the pattern of the tilt-grating is the extension of Equation (3),

$$\sin\beta_m = \frac{m\lambda}{d} \sqrt{1 + (\tan\beta_i)^2} \sin\alpha + \sin\beta_i. \quad (5)$$

It is the challenge to describe the curved pattern.

3.2.2. Rotating Grating CW Around X Axis, Then Rotating Grating CW/CCW Around Z Axis

Experiment-6: after rotating the grating around the X axis 55° CW, rotating the grating CW around Z axis 60° (Figure 6b)

Figure 6. Grating rotates CW around X axis by 55° (a), then rotates grating CW around Z axis, Patterns due to CW rotation by 60° (b)

Figure 6b shows the pattern is curved upwards, expanded and inclined towards the horizontal axis.

Experiment-7: after rotating the grating CW around the X axis by 55° (Figure 7a), rotate the grating CCW around Z axis by 70° (Figure 7b)

Figure 7. Grating rotates CW around X axis by 55° (a), then rotates grating CCW around Z axis Patterns due to CCW rotation by 70° (b)

Observation: Figure 7b shows the patterns are curved downwards, expanded and inclined towards the horizontal axis.

Mathematic Description: After rotating the grating CW around the X axis by the angle α , rotating the tilt-grating around the Z axis. The Z component create the expanded patterns, while the Y components create the curved patterns. When rotating the tilt-grating around the Z axis by an angle γ_i , the mathematic equation describing the expansion of the pattern of the grating is the extension of Equation (3),

$$\sin\gamma_m = \frac{m\lambda}{a} \sqrt{1 + (\tan\gamma_i)^2} \cos\alpha + \sin\gamma_i. \quad (6)$$

It is the challenge to describe the curved pattern.

Conclusion: the patterns are different when the tilt-grating rotates CW and CCW around the Y axis and around the Z axis.

3.2.3. Rotating Grating CCW Around X Axis, Then Rotating Grating CW/CCW Around Y Axis

Rotate the grating CCW around the X axis by 50° , Figure 5a shows its pattern. Then perform the following 2 experiments respectively.

Experiment-8: after rotating the grating around the X axis by 50° CCW, rotate the grating CW around Y axis by 45° (Figure 8b)

Figure 8. after rotating grating CCW around X axis by 50° (a), then rotates grating around Y axis:

Patterns due to *CW* rotation by 45° (b)

Observation: Figure 8b shows the patterns are curved towards the left, expanded and inclined towards the vertical axis.

Experiment-9: after rotating the grating CCW around the X axis by 50° (Figure 9a), rotate the grating CCW around Y axis by 75° (Figure 9b)

Figure 9. after rotating grating CCW around X axis by 50° (a), then rotates grating around Y axis:

Patterns due to CCW rotation by 75° (b)

Observation: the patterns are curved towards the left, expanded and inclined towards the vertical axis.

3.2.4. Rotating Grating CCW Around X Axis, Then Rotating Grating CW/CCW Around Z Axis

Experiment-10: after rotating the grating CCW around the X axis by 50° (Figure 10a), rotate the grating CW around Z axis by 60° (Figure 10b)

Figure 10. Grating rotates CCW by 50° around X axis (a),
then rotates grating CW around Z axis by 60° (b)

Observation: the pattern is curved, expanded and inclined towards the horizontal axis (Figure 10b).

Experiment-11: after rotating the grating CCW around X axis by 50° (Figure 11a), then rotate the grating CCW around Z axis by 60° (Figure 11b)

Figure 11. Grating rotates CCW around X axis by 50° (a),
then rotates grating CCW around Z axis by 60° (b)

Observation: The patterns expanded, curved and inclined towards the horizontal direction (Figure 11b).

3.2.5. Rotating Grating CW Around Y Axis, Then Rotating Grating CW/CCW Around Z axis

Experiment-12: after rotating CW the grating around Y axis by 45° (Figure 12a), rotate the grating CW around Z axis by 45° (Figure 12b)

Figure 12. Rotating Grating CW around Y axis (a), then rotates grating CW around Z axis by 45° (b)

Experiment-13: after rotating the grating CW around Y axis by 45° (Figure 13a), rotate the grating CCW around Z axis by 55° (Figure 13b)

Figure 13. Rotating Grating CW around Y axis (a), then rotates grating CCW around Z axis by 45° (b)

Observation: We observe that the patterns are expanded (due to the rotating around Y axis) and curved (due to the rotating around Z axis).

It is the challenge to describe mathematically the curvatures of the patterns (Figure 12b and 13b).

3.2.6. Rotating Grating CCW Around Y Axis, Then Rotating Grating CW/CCW Around Z axis

Experiment-14: after rotating the grating around Y axis CCW by 45° (Figure 14a), rotate the grating CW around the Z axis (Figure 14b)

Figure 14. Rotating Grating CCW around Y axis by 45° (a), then rotates grating CW around Z axis by 65° (b)

Experiment-15: after rotating the grating CCW around Y axis by 45° (Figure 15a), rotate the grating CCW around the Z axis (Figure 15b)

Figure 15. Rotating Grating CCW around Y axis by 45° (a), then rotates grating CCW around Z axis by 65° (b)

It is the challenge to describe the curvature of the patterns.

3.3. Rotating Grating Around Three Axis: Non-Uniform Pattern

Next, we rotate the 1D-grating around 3 axes. By rotating the grating CW and CCW around X axis, CW and CCW around Y axis, and CW and CCW around Z axis, besides the phenomena of the curved, expanded, inclined and mirror-symmetric patterns, we observed the non-uniform-spacing patterns as shown by Experiment-16 to 23 in Figure 16 to Figure 23. Although in Experiment-16 to 23, we use the specific discrete angles for rotating around each axis, one can rotate the grating either with any other discrete angles or continuously rotating the grating around any axis, for example the Z axis (attached Video).

We perform Experiment-16 to 19 starting with rotating the grating CW 45° around the X axis (Figure 04b), and Experiment-20 to 23 starting with rotating the grating CCW 45° around the X axis (Figure 04c). Figure 04a shows the pattern before rotating the grating.

Figure 04. Patterns: before rotating (a); rotating grating 45° around X CW (b) and CCW (c)

3.3.1. Rotating Grating CW Around X Axis by 45° , Then Rotating Around Other Two axes Sequentially

From the orientation of the grating (Figure 04b), performing the following four Experiment-16 to -19, respectively: rotating the grating CW and CCW around the Y axis, and CW and CCW around Z axis sequentially.

Experiment-16: Rotating the grating: CW X (45°) + CW Y (45°) + CW Z (70°)

Rotate the grating CW around Y axis and CW around Z axis (Figure 16a)

Figure 16. Patterns: (a) rotating grating CW around X axis by 45° and CW around the Y axis by 45° ;
 (b) rotating grating CW 45° around X, CW 45° around Y axis and CW around Z axis by 70°

Observation: Figure 16a shows the pattern of the grating after rotating around 2 axes, the X and the Y axes. The comparison between Figure 04b and Figure 16a shows that the second rotation (around the Y axis) causes the pattern expanded and curved towards the left. Figure 16b shows the pattern of the grating after rotating around 3 axes, the X axis, Y axis and the Z axis. The third rotation around the Z axis cause expanding more.

Experiment-16b shows the most significant novel phenomena that, the very first time, the pattern is expanded non-uniformly. More specifically, the expansion of the spacing between the adjacent diffraction orders increase gradually from the bottom-portion to the top portion of the pattern.

Experiment-17: Rotating the grating: CW X (45°) + CW Y (45°) + CCW Z (75°)

Rotate the grating CW around Y axis and CCW around Z axis (Figure 17)

Figure 17. Patterns: rotating grating CW around X by 45° , CW around Y axis by 45°
 and CCW around Z axis by 70°

Observation: Experiment-17 shows that the pattern is expanded non-uniformly. Namely, the expansion of the spacing between the adjacent diffraction orders increase gradually from the bottom-portion to the top portion of the pattern.

Experiment-18: Rotating the grating: CW X (45°) + CCW Y (40°) + CW Z (70°)

Figure 18. Patterns: rotating grating CW around X by 45° , CCW around Y axis by 40° and CW around Z axis by 70°

Observation: Experiment-18 shows that the pattern is expanded non-uniformly. Namely, the expansion of the spacing between the adjacent diffraction orders increase gradually from the top-portion to the bottom portion of the pattern.

Experiment-19: Rotating the grating: CW X (45°) + CCW Y (40°) + CCW Z (70°)

Figure 19. Patterns: rotating grating CW around X by 45° , CCW around Y axis by 40° and CCW around Z axis by 70°

Observation: Experiment-19 shows that the pattern is expanded non-uniformly. Namely, the expansion of the spacing between the adjacent diffraction orders increase gradually from the top-portion to the bottom portion of the pattern.

3.3.2. Rotating Grating CCW Around X Axis by 45° , Then Rotating Around Other Two axes Sequentially

Rotating the grating CCW around the X axis by 45° first, then performing the following four Experiment-20 to -23, respectively: rotating the grating CW and CCW around the Y axis, and CW and CCW around Z axis sequentially.

Experiment-20: Rotating the grating: CCW X (45°) + CW Y (45°) + CW Z (70°)

Figure 20. Rotating grating CCW around X by 45° , CW around Y axis by 45° and CW around Z axis by 70°

Observation: Experiment-20 shows that after rotating around 3 axes, the pattern curved, expanded and inclined. The novel phenomena are that the patterns are expanded non-uniformly. More specifically, the expansion of the spacing between the adjacent diffraction orders increase gradually from the bottom-portion to the top portion of the pattern.

Experiment-21: Rotating the grating: CCW X (45°) + CW Y (45°) + CCW Z (70°)

Rotate the grating CW around Y axis and CCW around Z axis (Figure 21)

Figure 21. Patterns: rotating grating CCW around X by 45° , CW around Y axis by 45°
and CCW around Z axis by 70°

Observation: Experiment-6 shows that the pattern curved, expanded and inclined. The expansion is non-uniform. Namely, the expansion of the spacing between the adjacent diffraction orders increase gradually from the bottom-portion to the top-portion of the pattern.

Experiment-22: Rotating the grating: CCW X (45°) + CCW Y (45°) + CW Z (70°)

Rotate the grating CCW around Y axis and CW around Z axis (Figure 22)

Figure 22. Patterns: rotating grating CCW around X by 45° , CCW around Y axis by 45°
and CW around Z axis by 70°

Observation: Experiment-22 shows that the pattern is expanded non-uniformly. Namely, the expansion of the spacing between the adjacent diffraction orders increase gradually from the top-portion to the bottom-portion of the pattern.

Experiment-23: Rotating the grating: CCW X (45°) + CCW Y (45°) + CCW Z (70°)

Rotate the grating CCW around Y axis and CCW around Z axis (Figure 23)

Figure 23. Patterns: rotating grating CCW around X by 45° , CCW around Y axis by 45° and CCW around Z axis by 70°

Observation: Experiment-23 shows that the pattern is expanded non-uniformly. Namely, the expansion of the spacing between the adjacent diffraction orders increase gradually from the top-portion to the bottom-portion of the pattern.

3.4. Video: Continuously Rotating Grating

The video shows, the first time, how the dynamic characteristics of the diffraction patterns continuously vary when the grating is rotating continuously around three axes.

We start from the orientation of the grating, i.e., the grating is rotated clockwise 45 degrees around the X axis and rotated clockwise 45 degrees around the Y axis.

The diffraction pattern is shown.

Then continuously rotating the grating clockwise around the Z axis, i.e., the vertical direction.

The diffraction patterns change gradually in three aspects continuously and simultaneously:

First aspect, the whole pattern rotates.

Second aspect, the spacings between the adjacent diffraction orders of the pattern are expanded.

Third aspect, the expansions of the spacings between the adjacent orders of the patterns are non-uniform. The video shows that the spacings of the top-portion of the pattern is larger than that of the bottom-portion.

Then go back to the starting orientation and rotate the grating counterclockwise. The diffraction patterns still vary in three aspects:

First and Second aspects are the same. Namely, the whole pattern is rotating, and the distances between fringes are expanded.

Third aspect, the expansions of the spacings between the adjacent orders of the patterns are non-uniform. More specifically, the spacings of the top-portion of the pattern are larger than that of the bottom-portion.

This phenomenon is extraordinary and challenges the existing interpretations of grating.

4. Discussion and Conclusion

We introduce the 3-axis-rotation apparatus and associated coordinate system, by which one can rotate CW and CCW the double slit/cross-double slit/grating/cross-grating to desired orientations. The apparatus makes it is possible to thoroughly study the orientation-dependence of the patterns of the grating without difficulty.

The preliminary experiments of this article:

- (1) show the first time, the non-uniform spacing between adjacent diffraction orders. More specifically, the spacings are gradually increase either from the top-portion to the bottom-portion of the pattern, or from the bottom-portion to the top-portion of the pattern.
- (2) show that the phenomena of the non-uniform spacings exist commonly.
- (3) show that the non-uniform spacing are caused by the third-time rotation, namely the grating rotates around the third axis.

The phenomena challenge both the standard theory of the 1D-grating for the normal incident light beam and the theories of 1D-grating for the oblique incident light beam [1-3].

We suggest that a complete mathematical model should contains three rotation angles as parameters and should be able to describe all phenomena of the orientation-dependence of the patterns consistently. The phenomena would provide the comprehensive information/data for theorists.

The effects of the orientations on the patterns may be utilized in the applications.

References

- [1] James E. Harvey and Cynthia L. Vernold, "Description of Diffraction Grating Behavior in Direction Cosine Space", *Applied Optics* 37(34):8158-8160. DOI: 10.1364/AO.37.008158, Dec. 1998.
- [2] Ninad R. Jetty, Akash Suman and Rajesh B. Khaparde, "Novel cases of diffraction of light from a grating: Theory and experiment", *American Journal of Physics* 80(684):972. DOI: 10.1119/1.4737854, 2012.
- [3] Georg Heuberger, et al., "Light diffraction from a phase grating at oblique incidence in the

intermediate diffraction regime”, *Applied Physics B* 127:72,

<https://doi.org/10.1007/s00340-021-07620-x>, 2021.

- [4] Hui Peng, “Observations of Cross-Double-Slit Experiments.” *Intern. J. of Physics*, vol. 8, no. 2: 39-41. doi: 10.12691/ijp-8-2-1, 2020.
- [5] Hui Peng, “Experimental Study of Mystery of Double Slit --- Comprehensive Double Slit Experiments”. *Intern. J. of Physics*, vol. 9, no. 2: 114-127. doi: 10.12691/ijp-9-2-6, 2021.
- [6] Hui Peng. Double Slit Experiment Still Has Much to Offer (6): Curved, Expanded and Inclined Interference Patterns —Dynamic Double Slit/Cross-Double Slit Experiments. hal-03338628, 2021
- [7] Hui Peng, “Curved, expanded and inclined patterns of dynamic double slit/cross-double slit/grating experiments”, *J. Eng.* 160–179. <https://doi.org/10.1049/tje2.12101>, 2021.
- [8] Hui Peng. Double Slit Experiment Still Has Much to Offer (9): —Continuously Curved Diffraction Patterns of 2D-Cross-Grating Experiments. hal-03425563, 2021.
- [9] Hui Peng, “Non-Uniform Diffraction Pattern of Grating Experiments---Rotating Grating Around Three Axes (3)”, Research Square, preprint, DOI: <https://doi.org/10.21203/rs.3.rs-1281907/v2>, 2022.