Non-Uniform Diffraction Pattern of Grating Experiments—Rotating Grating Around Three Axes (3)

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Research Article

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Non-Uniform Diffraction Pattern of Grating Experiments ---Rotating Grating Around Three Axes (3)

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Abstract The orientation-dependence of the interference/diffraction patterns of the 1D-double slit, 2D-cross-double slit, 1D-grating and 2D-cross-grating experiments have been studied experimentally and theoretically. The universal phenomena of the curved, expanded, inclined and mirror-symmetric patterns were reported. However, the above experiments were limited to certain orientations, namely rotating the diaphragm/grating around either one axis or two axes. Here we show that, for certain orientations by rotating the grating around 3 axes, the spacings between adjacent diffraction orders are non-uniform. Namely, from “one end” of the pattern to “other end”, the spacings between adjacent diffraction orders gradually increase. This extraordinary phenomenon challenges the existing theories.

The above observed phenomena provide the comprehensive phenomena to theoretical study of the grating experiments. We suggest that the complete mathematical model should contain three rotation angles as parameters and should be able to describe the phenomena of the non-uniform-spacing, curved, expanded, inclined and mirror-symmetric diffraction patterns consistently.

Keywords: grating experiment, cross-grating experiments, diffraction pattern, diffraction order, normal incident light beam, oblique incident light beam, orientation-dependence,

Declaration: This article has no potential conflicts of interesting

1. Introduction

The orientation-dependence, for certain orientations, of the interference patterns of the 1D-double slit and 2D-cross-double slit experiments have been studied experimentally and theoretically [1] [2] [3] [4]. The universal phenomena of the curved, expanded and inclined patterns were reported.

Recently, we have introduced the 3-axis-rotation apparatus, by which, the orientation-dependence of the diffraction patterns of the 1D-grating and 2D-cross-grating experiments have been studied [5] [6]. The simultaneously curved, expanded, inclined and mirror-symmetric diffraction patterns (hereafter denoted as “pattern”) emerged in the grating experiments. 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 1D-grating and 2D-cross-grating around two axes.

In this article, we study the orientation-dependence of the patterns completely by utilizing the 3-axis-rotation apparatus. The 1D-grating is rotated around three axes sequentially and respectively. The systematic study of the patterns is achieved intuitively.

We report, the very first time, the new phenomena that for certain orientations by rotating the grating around 3 axes respectively, the spacings between adjacent diffraction orders are *non-uniform*.

The phenomena challenge both the standard theory of the 1D-grating for the normal incident light beam and the theories of the 1D-grating for the oblique incident light beam [7] [8] [9] [10].

The novel phenomena of the continuously curved, expanded, inclined, mirror-symmetric and non-uniform spacing patterns provide the comprehensive phenomena/information to theoretically study the double slit/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.

2. Experiments: Rotating 1D-grating Around 3 Axes

In the previous articles [5] [6], the grating has been rotated around 2 axes. In this article, we rotate the 1D-grating around 3 axes. By rotating the grating clockwise (CW) and counterclockwise (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-1 to 8 in Figure 1 to Figure 8. Although in Experiment-1 to 8, 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.

We perform Experiment-1 to 4 starting with rotating the grating CW 45° around the X axis (Figure A(b)), and Experiment-5 to 8 starting with rotating the grating CCW 45° around the X axis (Figure A(c)). Figure A(a) shows the pattern before rotating the grating.

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

2.1. Rotating Grating CW 45° Around X Axis, Then Rotating Around Other Two axes

Sequentially

From the orientation of the grating (Figure A(b)), performing the following four Experiment-1 to -4, respectively: rotating the grating CW and CCW around the Y axis, and CW and CCW around Z axis sequentially.

Experiment-1: 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 1).

Figure 1. Patterns: (a) rotating grating CW 45° around X axis and CW 45° around the Y axis.

(b) rotating grating CW 45° around X, CW 45° around Y axis and CW 70° around Z axis

Observation: Figure 1a shows the pattern of the grating after rotating around 2 axes, the X and the Y axes. The comparison of Figure A(b) and Figure 1a shows that the second rotation (around the Y axis) causes the pattern expanded and curved towards the left.

Figure 1b 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-1 shows, the first time, the most significant novel phenomena that the pattern is expanded non-uniformly. More specifically, the expansion of the spacing between the adjacent diffraction orders increase gradually from the bottom-portion (below the zero order) to the top portion (above the zero order) of the pattern.

Experiment-2: Rotating the grating: CW X (45°) + CW Y (45°) + CCW Z (70°)

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

Figure 2. Patterns: rotating grating CW 45° around X, CW 45° around Y axis
and CCW 70° around Z axis

Observation: Experiment-2 shows that the pattern is expanded non-uniformly. Namely, the expansions of the spacings between the adjacent diffraction orders increase gradually from the bottom-portion to the top portion of the pattern.

Experiment-3: Rotating the grating: CW X (45°) + CCW Y (40°) + CW Z (70°)

Figure 3. Patterns: rotating grating CW 45° around X, CCW 40° around Y axis
and CW 70° around Z axis

Observation: Experiment-3 shows that the pattern is expanded non-uniformly. Namely, the expansions of the spacings between the adjacent diffraction orders increase gradually from the top-portion to the bottom portion of the pattern.

Experiment-4: Rotating the grating: CW X (45°) + CCW Y (40°) + CCW Z (75°)

Figure 4. Patterns: rotating grating CW 45° around X, CCW 40° around Y axis
and CCW 75° around Z axis

Observation: Experiment-4 shows that the pattern is expanded non-uniformly. Namely, the expansions of the spacing between the adjacent diffraction orders increase gradually from the top-portion to the bottom-portion of the pattern.

2.2. Rotating Grating CCW 45° Around X Axis, Then Rotating Around Other Two Axes Sequentially

Starting with rotating the grating CCW 45° around the X axis (Figure A(c)) first, then performing the following four Experiment-5 to -8, respectively: rotating the grating CW and CCW around the Y axis, and CW and CCW around Z axis sequentially.

Experiment-5: Rotating the grating: CCW X (45°) + CW Y (45°) + CW Z (70°)

Figure 5. Patterns: (a) rotating grating CCW 45° around X axis and CW 45° around the Y axis.

(b) rotating grating CCW 45° around X, CW 45° around Y axis and CW 70° around Z axis

Observation: Figure 5a shows the pattern of the grating after rotating around 2 axes, the X and the Y axes. The comparison of Figure A(c) and Figure 5a shows that the second rotation (around the Y axis) causes the pattern expanded and curved towards the right.

Figure 5b 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 and non-uniform.

Experiment-5 shows the phenomena that 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-6: Rotating the grating: CCW X (45°) + CW Y (45°) + CCW Z (7°)

Rotate the grating CW around Y axis and CCW around Z axis (Figure 6)

Figure 6. Patterns: rotating grating CCW 45° around X, CW 45° around Y axis
and CCW 70° around Z axis

Observation: Experiment-6 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-7: 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 24c)

Figure 7. Patterns: rotating grating CCW 45° around X, CCW 45° around Y axis
and CW 70° around Z axis

Observation: Experiment-7 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-8: 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 8)

Figure 8. Patterns: rotating grating CCW 45° around X, CCW 45° around Y axis
and CCW 70° around Z axis

Observation: Experiment-8 shows that the pattern is expanded non-uniformly. Namely, the expansions of the spacings between the adjacent diffraction orders increase gradually from the top-portion to the bottom-portion of the pattern.

3. Discussion

The preliminary experiments of this article show, the first time:

- (1) the non-uniform spacings 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) the phenomena of the non-uniform spacings exist regularly.
- (3) based on Experiment-1 to -8, the rotation CCW around the axis Y makes the spacings increase from the top-portion to the bottom-portion of the patterns. The rotation CW around the axis Y makes the spacings increase from the bottom-portion to the top-portion of the patterns.

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. For references, for example, see [7] [8] [9] [10] and references within.

4. Recent Developments of Research on Double Slit and Grating Experiments

Feynman stated that Young's double slit experiment was the mystery of the quantum mechanics. It is interesting to show how the study of the mystery of the double slit experiments has been progressed recently.

4.1. Recent Developments of Double Slit Experiments

*) Pattern of the standard double slit experiments:

*) Patterns of the cross-double slit experiments [11] [12] [13]:

*) Curved patterns of the same diaphragm of the double slit [2] [14]:

*) Expanded patterns of the same diaphragm of the double slit [1]:

*) Curved and Expanded patterns of the same diaphragm of the cross-double slit [2]:

*) Curved, expanded and inclined patterns of the same diaphragm of the double slit [15] [16]:

*) Mirror-symmetry Patterns of the same diaphragm of the double slit [6]:

*) before passing through double slit, light beam behaves as particles, photons [17]

*) before landing on the screen, light beam behaves as particles, photons.

*) Violating Trajectory Theory: Shield contacting Diaphragm of double slit [18]

4.2. Recent Developments of Grating Experiments

*) Standard patterns of 1D-grating and 2D-Cross-Grating

(B1) Recent Developments of 1D-Grating Experiments

*) Expanded diffraction patterns of the same 1D-grating [16] [5]:

*) Curved patterns of the same 1D-grating [5][4]:

*) Curved, expanded and inclined patterns of the same 1D-grating [16] [5]

(B2) Recent Developments of 2D-Cross-Grating Experiments

*) Curved and expanded patterns of the same 2D-cross-grating [19] [6]:

*) Curved, expanded and inclined patterns of the same 2D-cross-grating [6]

*) Mirror-symmetric patterns of the same 2D-cross-grating [6]:

*) Light beam behaving as particles before striking on screen: Grating experiments [6]

*) non-uniform spacing between adjacent diffraction orders of the pattern (this article).

Appendixes

A. Three-Axis-Rotation Apparatus: Rotating Double-slit/Grating Around Three Axes

A1. Three-Axis-Rotation Apparatus

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 cross-grating. For this aim, we use the three-axis-rotation apparatus [5] [6] that can rotate the double slit/cross-double slit and grating/cross-grating around 3 axes to reach desired orientations (Figure A1).

Figure A1. Experimental setup: 3-axis-rotation apparatus:
grating can rotate around Z axis; around Y axis; around X axis.

The Y and Z axes are perpendicular to each other always; The Y and X axes are perpendicular to each other always. Figure 2b shows the original orientation of the grating. Figure 2c shows that the grating rotates around the X axis. Figure 2d shows that the cross-grating, the ring/cross-grating, and the frame/ring/cross-grating rotate around the X axis, the Y axis and the Z axis respectively.

The shortcoming of the above apparatus is that the thick ring may block light beam for certain orientation. To avoid it, one can make the ring as thin as possible to minimize the blockage. An alternative apparatus shown in Figure A2 is convenient to perform the experiments

Figure A2. The alternative 3-axis rotation apparatus

With those apparatuses, the orientation-dependence of the patterns of the cross-grating can be studied thoroughly and conveniently, and novel phenomena are shown.

A2. Coordinate System

To study the orientation-dependence of the patterns, we introduce the coordinate system and the original orientation of the 3-axis-rotation apparatus and grating (Figure A1a).

Coordinate System: The rotation axis of the frame defines the Z axis; the rotation angles γ around the Z axis are either “Clockwise γ ” (denoted as “CW γ ”) or “Counterclockwise γ ” (denoted as “CCW γ ”). The frame can be rotated CW and CCW around Z axis between $0^\circ \leq \gamma \leq 360^\circ$. The rotation axis of the

ring defines the Y axis, the rotation angles β are either “CW β ” or “CCW β ”. The ring can be rotated CW and CCW around Y axis between $0^\circ \leq \beta \leq 360^\circ$. The normal vector of the cross-grating defines the X axis. The rotation angles α are either “CW α ” or “CCW α ”. The cross-grating can be rotated CW and CCW around X axis between $0^\circ \leq \alpha \leq 360^\circ$.

The X axis and the Y axis are always perpendicular to each other. The Y axis and the Z axis are always perpendicular to each other. The X axis changes its direction when the ring rotates around the Y axis and when the frame rotates around the Z axis. The Y axis changes its direction when the frame rotates around the Z axis. The Z axis keeps the same direction always. The laser beam points to the same direction always.

A3. Original orientation of the grating

At the original orientation, the X, Y and Z axes form the Cartesian coordinate system (Figure 3a), denoted it as the original coordinate system. The horizontal slits, denoted as S1, of the cross-grating are along the Y axis and creates the vertical pattern P1, while the vertical slits, denoted as S2, of the cross-grating are along the Z axis and create the horizontal pattern P2 (Figure 3b and 3c). The laser source is on the X axis, i.e., the light beam is normally incident on the plane of the grating, referred it as the original orientation.

Figure A3. Apparatus/Coordinate (a), Cross-grating (b) and Pattern (c)

A4. Direction of Rotation: to define the direction of the CW and CCW rotation, we introduce the right-hand rule that states 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 4).

Figure A4. Right-hand rule for determining direction of rotation

A5. Rotating Grating Around Three Axis

To study systematically the orientations-dependence of the interference patterns and diffraction patterns (hereafter denoted both as the “patterns”) of the 1D-double slit/2D-cross-double slit/1D-grating/2D-cross-grating, the effects of the orientations on the patterns need to be considered when the following rotations are performed:

(A) Starting from the original orientation, then, rotating the grating around one axis only:

(A1) Rotate the grating around the X axis: CW α and CCW α , respectively

(A2) Rotate the grating/ring around the Y axis: CW β and CCW β , respectively

(A3) Rotate the grating/ring/frame around the Z axis: CW γ and CCW γ , respectively

(B) Starting from the original orientation, then, rotating the grating around 2 axes, respectively:

(B1) Rotate (CW α and CCW α) the grating around the X axis, then, rotate the grating around the Y and Z axes, respectively,

X axis (CW α):

Y axis (CW β)

Y axis (CCW β)

Z axis (CW γ)

Z axis (CCW γ)

X axis (CCW α):

Y axis (CW β)

Y axis (CCW β)

Z axis (CW γ)

Z axis (CCW γ)

(B2) Rotate (CW β and CCW β) the grating/ring around the Y axis, then, rotate the grating around the Z and X axes, respectively,

Y axis (CW β):

Z axis (CW γ)

Z axis (CCW γ)

X axis (CW α)

X axis (CCW α)

Y axis (CCW β):

Z axis (CW γ)

Z axis (CCW γ)

X axis (CW α)

X axis (CCW α)

(B3) Rotate (CW γ and CCW γ) the grating/ring/frame around the Z axis, then, rotate the grating around the X and Y axes, respectively,

Z axis (CW γ):	Z axis (CCW γ):
X axis (CW α)	X axis (CW α)
X axis (CCW α)	X axis (CCW α)
Y axis (CW β)	Y axis (CW β)
Y axis (CCW β)	Y axis (CCW β)

(C) Starting from the original orientation, then, rotating the grating around 3 axes respectively:

(C1) Rotate (CW α and CCW α) the grating around the X axis, then, rotating the grating around the Y axis and Z axis, and the Z axis YY axis, respectively,

X axis (CW α):	X axis (CCW α):
Y axis (CW β) + Z axis (CW γ)	Y axis (CW β) + Z axis (CW γ)
Y axis (CW β) + Z axis (CCW γ)	Y axis (CW β) + Z axis (CCW γ)
Y axis (CCW β) + Z axis (CW γ)	Y axis (CCW β) + Z axis (CW γ)
Y axis (CCW β) + Z axis (CCW γ)	Y axis (CCW β) + Z axis (CCW γ)
Z axis (CW γ) + Y axis (CW β)	Z axis (CW γ) + Y axis (CW β)
Z axis (CW γ) + Y axis (CCW β)	Z axis (CW γ) + Y axis (CCW β)
Z axis (CCW γ) + Y axis (CW β)	Z axis (CCW γ) + Y axis (CW β)
Z axis (CCW γ) + Y axis (CCW β)	Z axis (CCW γ) + Y axis (CCW β)

(C2) Rotate (CW β and CCW β) the cross-grating/ring around the Y axis, then, rotating the cross-grating around the Z axis + X axis, and the X axis + Z axis, respectively,

Y axis (CW β):	Y axis (CCW β):
Z axis (CW γ) + X axis (CW α)	Z axis (CW γ) + X axis (CW α)
Z axis (CW γ) + X axis (CCW α)	Z axis (CW γ) + X axis (CCW α)
Z axis (CCW γ) + X axis (CW α)	Z axis (CCW γ) + X axis (CW α)
Z axis (CCW γ) + X axis (CCW α)	Z axis (CCW γ) + X axis (CCW α)
X axis (CW α) + Z axis (CW γ)	X axis (CW α) + Z axis (CW γ)
X axis (CW α) + Z axis (CCW γ)	X axis (CW α) + Z axis (CCW γ)
X axis (CCW α) + Z axis (CW γ)	X axis (CCW α) + Z axis (CW γ)
X axis (CCW α) + Z axis (CCW γ)	X axis (CCW α) + Z axis (CCW γ)

(C3) Rotate (CW γ and CCW γ) the cross-grating/ring/frame around the Z axis, then, rotating the cross-grating around the X axis + Y axis, and the Y axis + X axis, respectively,

Z axis (CW γ):

X axis (CW α) + Y axis (CW β)

X axis (CW α) + Y axis (CCW β)

X axis (CCW α) + Y axis (CW β)

X axis (CCW α) + Y axis (CCW β)

Y axis (CW β) + X axis (CW α)

Y axis (CW β) + X axis (CCW α)

Y axis (CCW β) + X axis (CW α)

Y axis (CCW β) + X axis (CCW α)

Z axis (CCW γ):

X axis (CW α) + Y axis (CW β)

X axis (CW α) + Y axis (CCW β)

X axis (CCW α) + Y axis (CW β)

X axis (CCW α) + Y axis (CCW β)

Y axis (CW β) + X axis (CW α)

Y axis (CW β) + X axis (CCW α)

Y axis (CCW β) + X axis (CW α)

Y axis (CCW β) + X axis (CCW α)

When rotate the cross-grating, the ring and the frame, we always rotate CCW and CW respectively. For rotating around one axis, rotating CW and CCW creates the mirror-symmetry patterns.

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