Degenerate four-wave interferences and perfect blaze

R. Güther

Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztechnik,

Gustav-Kirchhoff-Str. 4, D-12489 Berlin, Germany

mailto:guether@fbh-berlin.de

We present a simple model for understanding the perfect blaze for diffraction with echelle gratings. Littrow diffraction at grating profiles with rectangular apex-angles implicates two pairs of counterpropagating light waves. The four waves show a rectangular pattern of interference fringes. Integer numbers of such fringes along both facets of a groove ensure perfect blazing with echelle gratings.

1 Introduction

A wanted feature of diffraction at echelle gratings is “perfect blaze”. Then the intensity into the “unwanted” diffraction orders is required to be zero, while a power absorption in the grating caused by finite conductivity of metals is accepted.

The first proof for perfect blaze simultaneously for both polarization cases of an echelle grating in Littrow mounting was given recently by B.H. Kleemann [1] with the help of electromagnetic diffraction theory.

Here we propose a simple model for understanding the perfect blaze, founded on degenerate four-wave-interference patterns and the matching of these patterns with the lengths of the facets of the echelle profile.

2 Laser: One-dimensional confinement of an interference pattern by mirrors

A simple example of the confinement of the interference pattern of a counterpropagating pair of waves are laser mirrors in the zeros of the interferences, as drawn in Fig. 1.

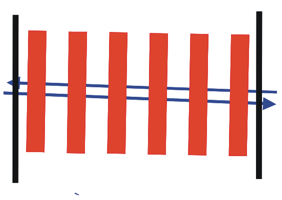

Fig. 1 *Confinement of interferences by mirrors along the zeros of the interference pattern.*

3 Littrow mounting for echelle gratings

The Littrow mounting configuration of grating diffraction generates a first pair of counterpropagating waves: the incident wave and the diffracted wave. The use of rectangular grating profiles in an echelle generates an array of retroreflectors in the grating. Then, in each groove a second pair of counterpropagating waves occurs as shown in Fig. 2. The interference pattern of the two pairs of waves is a rectangular pattern shown in Fig. 2. The concept of Fig. 1 of positioning the mirrors along

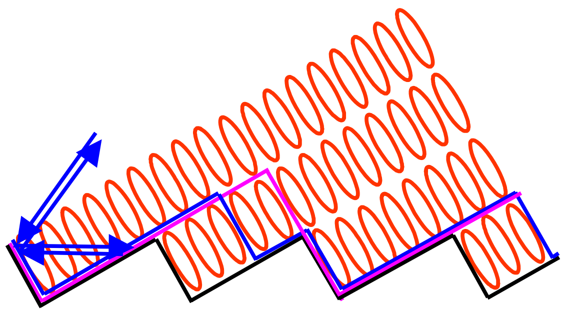

Fig. 2 *Rectangular interference pattern caused by two pairs of counterpropagating waves with nearly equal amplitudes.The black, violet or blue profile along the system of zeros are possible profiles of perfect blaze.*

the zeros for confinement is generalized to three examples for path possibilities for grating profiles in Fig. 2. The black profile is a simple blaze profile, the violet profile with doubled period is connected with higher order diffraction and the blue line is a possible new kind of profile. The main hypothesis of this work is the demand that integer numbers of fringes must occur along both facets of the blaze profile. For example: Black profile: Fringe number at left hand facet = 1, fringe number at right hand facet = 5; violet profile: fringe number at left hand facet = 2, fringe number at right hand facet = 10.

4 Grating profile design

The design of the grating profile requires the wavelength λ_0 of the blaze maximum, the Littrow diffraction order L and the integer numbers of interference fringes M and N along both facets. The relation between the three integers L,M and N is

$$M = N - L \tag{1}$$

In Fig. 2, the blaze angle β is defined by the positive value of the slope angle of the left hand facet. It is given by

$$\beta = 90° - \arccos\left[L/\left(M+N\right)\right]/2 \qquad (2)$$

and the grating constant g is given by

$$g = \frac{L\lambda_0}{2\sin\left(2\beta - 90°\right)} \qquad (3)$$

5 Comparison of different designs

Table 1 compares the design of the perfect blazing grating in [1] with the design obtained here (Example 1) using formulae (1-3). A second blaze configuration is applicable for λ_0 = 600 nm (Example 2.1) as well as for λ_0 = 900 nm (Example 2.2).

	λ_0 [nm]	L	M	N	β [°]	g [nm]
Paper [1]	193.3	89			84	8794
Example 1	193.3	89	1	90	83.983	8795.2
Example 2.1	600	87	3	90	79.653	27900
Example 2.2	900	58	2	60	79.653	27900

Tab. 1 *Comparison of electromagnetic design with interference fringe design and an example applicable for two wavelengths.The angle between the facets is 90°.*

6 Validity of the model

In the case of high order L and large N one facet of the grating profile is large in comparison to the wavelength. Geometrical optics and usual interference patterns determine the diffraction.

For small L, M, N the peaks and valleys of the grating profile have a distance in the range of a wavelength and a closer possibility of interaction exists. Therefore, the test of the fringe method for perfect blaze presented here by numerical electromagnetic calculations should be recommended especially in the case of finite conductivity of the grating material.

The examples of Tab. 1 were numerically tested for perfect blaze in [1], [2] and [3] for infinite and finite (grating materials: Example 1: Al; Example 2: Au) conductivity with the result of nearly a per mill efficiency in the unwanted diffraction orders only.

7 Diffraction efficiency for λ_0 = 900 nm

An example of diffraction efficiency of the last row of Tab. 1 is shown in Fig. 3. Maximum efficiency occurs nearly at β = 80°.

8 Summary

The model of an integer number of interference fringes along both facets of a blazed grating is a simple tool to predict perfect blazing. An increase of efficiency in the of order of 10-30% in comparison to usual chosen grating profiles can be assumed for some cases. The validity of the model has been tested with electromagnetic theory. The degree of validity between L=1 and L = 40 is not yet fully investigated.

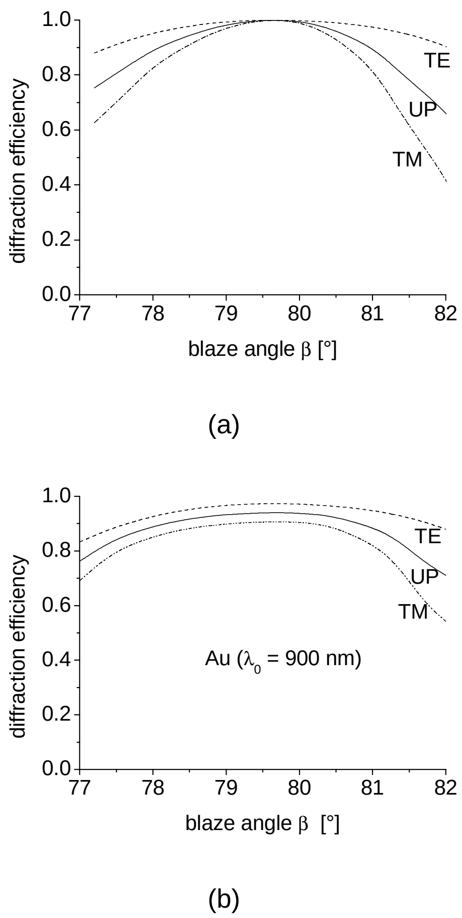

Fig. 3 *Diffraction efficiency of an echelle at λ_0 = 900 nm in dependence on the blaze angle β for TE-polarized light, TM-polarized light and unpolarized light (UP) with infinite conductivity (a) and finite conductivity (material: Au) (b) [3].*

Acknowledgement

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References

[1] B.H. Kleemann, „Perfect blazing with echelle gratings in TE- and TM- polarizations“, in *Optics Letters* **37(6)**: 1002-1004 (2012)

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[3] R. Güther, B.H. Kleemann, “Optical grating for Littrow mounting”, pending patent, DE 1020122087 72.9 (May 2012)