# IN-PLANE MOIRÉ TECHNIQUES IN THE EXPERIMENTAL SOLID MECHANICS – A SHORT SURVEY

**Jochen Naumann**

Chemnitz University of Technology, Faculty of Mechanical Engineering, Department of Solid Mechanics, Division Experimental Mechanics, 09107 Chemnitz, Germany

Corresponding author: jochen.naumann@mb.tu-chemnitz.de

## 1. Introduction

In the experimental mechanics the Moiré technique has developed to an established method. At the Chemnitz University moiré methods were investigated since 1965 [1].

To generate a moiré effect two gratings are superimposed. The moiré fringes can be interpreted as parameter curves, Fig. 1.

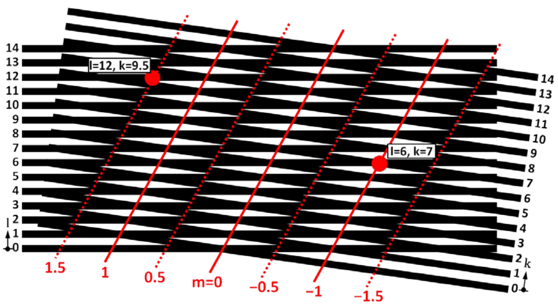


**Fig. 1:** Moiré fringes as parameter lines

Along each moiré fringe (order $m$) the difference $m = l - k$ of the line orders is constant.

## 2. Geometric Moiré

In the geometric moire technique an object grating deformed with the specimen and a reference grating are superimposed.

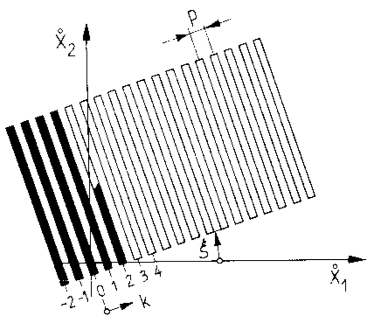


**Fig. 2:** Undeformed object grating

- The undeformed object grating, Fig. 2, is described by:

$$x_2^\circ = -\frac{x_1^\circ}{\tan\xi} + \frac{k \cdot p}{\sin\xi}$$

$x_i^\circ$ … co-ordinates **before** deformation

- As deformation process is assumed a homogeneous deformation state with the displacements $u_i$ and $u_{i,j} = const$ :

$$u_1(x_1, x_2) = u_{1,1} \cdot x_1 + u_{1,2} \cdot x_2$$
$$u_2(x_1, x_2) = u_{2,1} \cdot x_1 + u_{2,2} \cdot x_2$$

$x_i$ …co-ordinates **after** deformation

- The resulting deformed object grating is

$$x_2 = \frac{[-(1 - u_{1,1})\cos\xi + u_{2,1} \cdot \sin\xi]x_1 + k \cdot p}{(1 - u_{2,2})\sin\xi - u_{1,2} \cdot \cos\xi}$$

- The equation for the reference grating is

$$x_2 = -\frac{x_1}{\tan(\xi + \Delta\xi)} + \frac{l \cdot p \cdot (1 + \delta)}{\sin(\xi + \Delta\xi)}$$

$\delta, \Delta\xi$ ... mismatch of the reference grating

- Superposition of the deformed object grating and the reference grating with $m = l - k$ and for the simple case with $\delta = \Delta\xi = 0$ gives:

$$p \cdot m = x_1(u_{1,1} \cdot \cos\xi + u_{2,1} \cdot \sin\xi) + x_2(u_{1,2} \cdot \cos\xi + u_{2,2} \cdot \sin\xi)$$

respectively $u_\xi(x_1, x_2) = p \cdot m_\xi(x_1, x_2)$.

These moiré fringes are named as **isothetics**.

Fig. 3 shows an example for the ordering of isothetic fields [3]. In practice the ordering is realized intuitively and not by $m = l - k$.

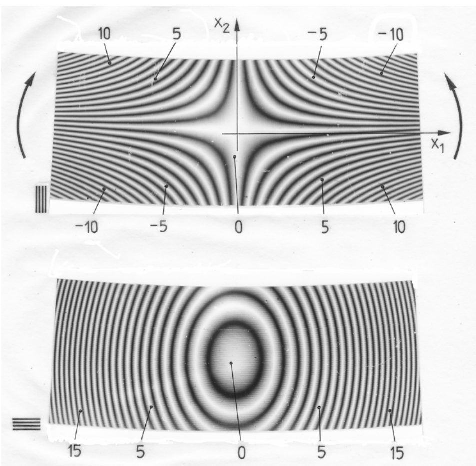


**Fig. 3:** Bending of a highelastic beam (13.3L/mm)

An important application of the geometric moiré is the visualization and measurement of large plastic deformations, Fig. 4, [3].

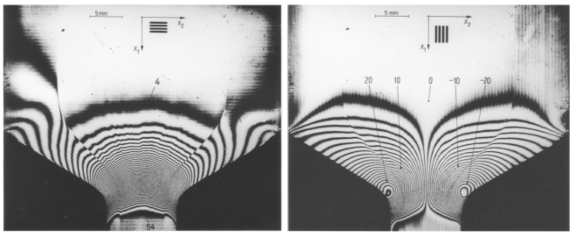

**Fig. 4**: Compound Extrusion Process of a bimetallic rod at room temperature (25 L/mm)

## 3. Interferometric Moiré

Optical foundations of the interferometric moiré are the diffraction at gratings and the optical interference [2],[3]. The generated fringes are called ”moiré finges” also. Two fundamental setups can be destinguished:

- Moiré fringe multiplication, Fig. 5a
- Moiréinterferometry, Fig. 5b

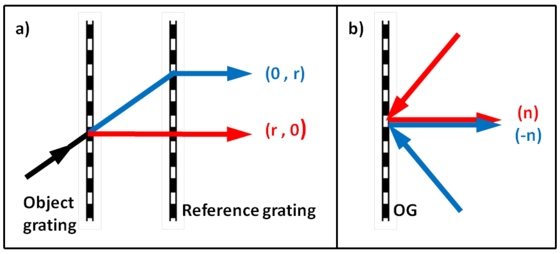


**Fig. 5:** a) Moiré fringe multiplication in transmitted light, b) Moiréinterferometry in reflected light

The sensitivity of moiré fringe multiplication is [2],[3]:

$$u_\xi(x_1,x_2) = p_{eff} \cdot m_\xi(x_1,x_2) \quad \text{with } p_{eff} = \frac{p}{r}$$

Fig. 6 shows the optical multiplication of an isothetic field. The object grating has only a real density of 50 L/mm.

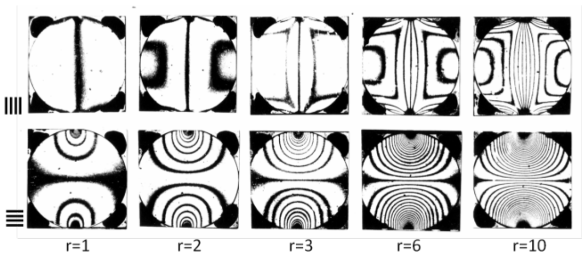


**Fig. 6:** Moiré fringe multiplication at a diametrically compressed disk [3]. 50..500 L/mm ($p_{eff}$=20..2 µm)

The Moiréinterferometry is world-wide used thanks to the activities of Post [6].

The experimental setup of moiréinterferometry , Fig. 5b, is characterized by two plane coherent waves diffracting at the deformed object grating in nearly the same direction. The resulting sensitivity is

$$u_\xi(x_1,x_2) = p_{eff} \cdot m_\xi(x_1,x_2) \quad \text{with } p_{eff} = \frac{p}{2n}$$

One of the most important application fields is the analysis of microstructures with high density object gratings, Fig. 7.

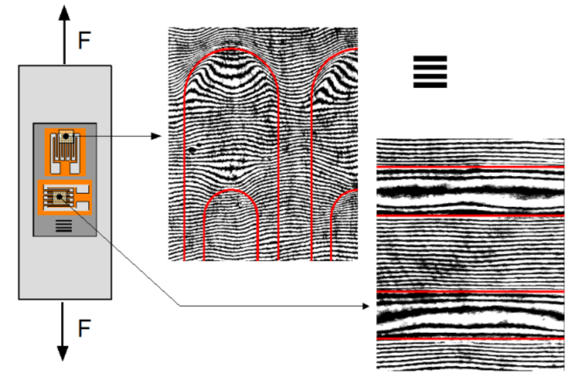


**Fig. 7**: Micro moiréinterferometry to investigate the strain transfer at a strain gage [4],[5]. 1400 L/mm, n=1, $p_{eff}$=357 nm

## References

[1] Ullmann, K., Anwendung des Moiréeffekts zur experimentellen Dehnungsanalyse. In: Beiträge zur Spannungs- und Dehnungsanalyse. vol. VI. Berlin 1970, pp. 59-112

[2] Naumann, J., Jantschke, B., Eine Theorie zur Moiréstreifenmultiplikation bei zwei überlagerten Gittern. Wiss. Z. d. Techn. Hochsch. Karl-Marx-Stadt 19(1977)3, 305-316

[3] Naumann, J., Grundlagen und Anwendung des In-plane-Moiréverfahrens in der experimentellen Festkörpermechanik. Fortschritt-Berichte, Reihe 18, Nr. 110. Düsseldorf 1992. 192 pp.

[4] Stockmann, M.: Mikromechanische Analyse der Wirkungsmechanismen elektrischer Dehnungs-messstreifen, Habilitationsschrift. 149 pp. In: Technische Universität Chemnitz, Institut für Mechanik. Bericht 3/2000 und http://archiv.tu-chemnitz.de/pub/2000/0049

[5] Stockmann, M.; Naumann, J.: Moiré Inter-ferometrie - Technique and Application, Testor 2005, 1, pp. 3-4

[6] Post, D., Han, B., Ifju, P.: High Sensitivity Moiré. New York, … 1994