Application note:

# Characterization of helical modes with SHSLab

## 1 Introduction

Laser beams with an orbital angular momentum (OAM) or so called optical vortex beams are light waves that can transduce rotational transversal forces, like, e.g., the turning of a door knob. The corresponding wave-front exhibits a helical structure and is usually described by Laguerre-Gauß modes. Figure 1 shows examples of helical mode wave-fronts with different helicity or topological charge.

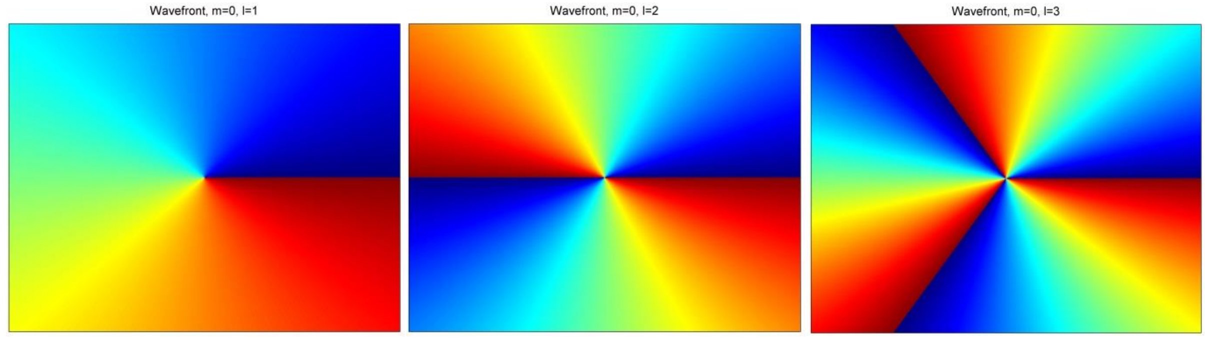


*Figure 1: Simulated helical modes with topological charge 1, 2 and 3.*

OAM beams can be formed by spiral phase plates, computer generated holograms, spatial light modulators, optical nano-antenna arrays or ring resonators. Applications include the rotation of particles trapped in an optical tweezer, the generation of weak microfluidic currents, STED microscopy and edge filtering by spiral phase contrast imaging, as well as improved optical data transmission and quantum cryptography. A versatile tool for the characterization of OAM beams is the Shack-Hartman wave-front sensor. The following sections describe the measurement and evaluation of helical wave-fronts with Optocraft's Shack-Hartman wave-front sensor SHSLab.

## 2 Experimental

The experimental setup is shown in figure 2: The light from a fiber coupled laser diode emitting at a wavelength of 635nm is collimated and passed through a spiral phase plate. The Shack-Hartmann wavefront Sensor SHSCam-BR-110-GE with a lateral resolution of 58 x 43 microlenses is placed directly behind the phase plate in order to minimize wave-front propagation effects. For the sake of simplicity, no relay optics was used. At first, a measurement with the phase plate removed from the beam path is taken and used as a reference for the subsequent measurements. Spiral phase plates with different topological charges of 1, 2 and 3 were measured.

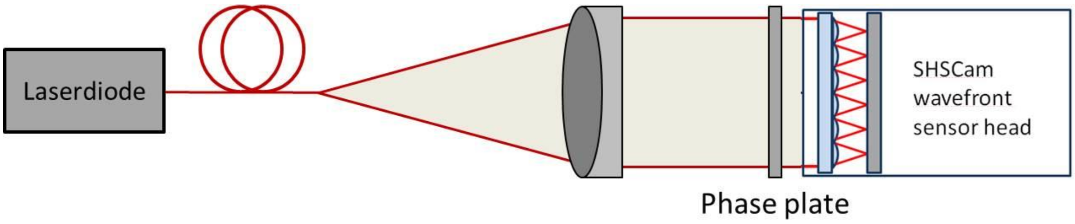


*Figure 2: Experimental Setup for helical wave-front measurement.*

## 3 Results

Due to the phase discontinuity present in helical wave-fronts, classic Shack-Hartmann wave-front reconstruction algorithms fail to calculate the helical wave-front. However, in order to analyze the influence of the spiral phase plate on the transmitted wave, it is usually sufficient to evaluate the spot displacement distribution detected by the wave-front sensor, which actually represents the gradient field of the corresponding wave-front.

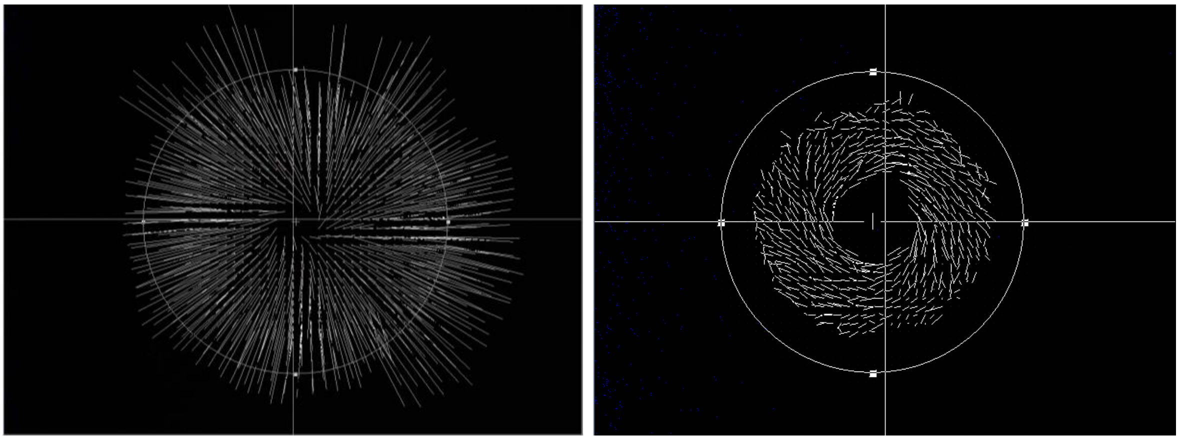

*Figure 3: Spot displacements as measured (left) and with tilt and defocus subtracted (right)*

The software SHSWorks offers a functionality to automatically remove tilt and defocus from the spot field, which is necessary for the analysis of the helical gradient field and the comparison to simulation results, see figure 3. Additionally, SHSWorks calculates the topological charge $l$ from the gradient field by evaluating the following path integral:

$$\oint \nabla_{\perp} W \cdot d\vec{r} = l \cdot \lambda$$

The table below shows the topological charges resulting from the measurement of 15 different spiral phase plates, consisting of 3 subgroups with a topological charge of 1, 2 and 3, respectively. The deviation of $l_{\text{measured}}$ from $l_{\text{design}}$ results from the discretization due to the limited number of sampling points.

| $l_{\text{design}}$ | $l_{\text{measured}}$ | | | | |
|---|---|---|---|---|---|
| 1 | 0,91 | 0,90 | 0,93 | 0,96 | 0,98 |
| 2 | 1,83 | 1,79 | 1,87 | 1,94 | 1,75 |
| 3 | 3,00 | 2,92 | 3,03 | 2,97 | 3,05 |

Further reading:

- M. Chen, C. Dainty: Reliability of detecting optical vortex with a Shack-Hartmann wavefront sensor in a scintillated vortex beam, in Proc. of SPIE Vol. 7476 (2009)
- M. Ritsch-Marte: Der Dreh mit dem Licht - Optische Spiralwellen und ihre Anwendungen, in Physik-Journal 14 (2015) Nr.1, S.31

  