SECTORIAL PERTURBATION OF SPIRAL VORTEX BEAMS

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Abstract

This research presents studies of the structural stability of a spiral beam subjected to sectoral perturbation. Sector perturbation causes a change in the direction of circulation of streamlines of the Poynting vector in the area of perturbation, which are caused by the array of vortices with negative topological charges. However, such perturbations do not cause a change in the orbital angular momentum of the beam, despite the increase in the number of vortex modes, and the perturbed beam remains structurally stable.

Theoretical information

In our research, we considered the passage of a spiral beam (SB) of light in the form of a seven-quantized triangle through a square sector. The complex amplitude of such a beam [1] can be represented as:

\[ w(x, y, z) = \sum_{m=-N/2}^{N/2} \sum_{n=-N/2}^{N/2} C_{m,n}(x, y) e^{i(m\phi + n\psi)} \]

where \( C_{m,n} \) — amplitude coefficients of Laguerre-Gaussian (LG) modes included in the composition of the SB, \( C_{m,n}(x, y) \) — amplitude coefficients of each perturbed LG mode by the sector, which are defined as:

\[ C_{m,n}(x, y) = C_{m,n} \left( x^2 + y^2 \right)^{-1/4} \]

The construction of the streamlines of the Poynting vector contains fine details of the process of destruction of the singular structure of the beam and manifests itself in the form of a pattern of critical points of the energy flow. Unlike the phase distribution, streamlines outline complex trajectories in the vicinity of singular points. The shape of the streamlines is determined by the phase gradient of the SB beam over the area of integration of the integral related to the complex conjugate of the beam and is written as:

\[ J(x, y) = \frac{1}{2} \left( \nabla \phi^* \cdot \nabla \phi \right) \]

Orbital angular momentum defined as [3]

\[ L_z = \int \left( \mathbf{E} \times \mathbf{E}^* \right) \cdot \mathbf{r} \, dS \]

and Informational Entropy [2]

\[ H(x, y) = \frac{1}{2} \sum_{m=-N/2}^{N/2} \sum_{n=-N/2}^{N/2} C_{m,n}^2 \log_2 \left( C_{m,n}^2 \right) \]

where \( C_{m,n} \) are normalized squared modes related to (2) modes by the relation \( C_{m,n} = C_{m,n} \left( x^2 + y^2 \right)^{-1/4} \).

Experimental setup

The experiment setup: laser 0.633 μm, P-polarizer, SLE — spatial light filter, L1 —4-f lens, L3 - triaxial lens with focal lengths f′=f=2cm, L6 — beam splitter, SLM1, L7, L8, a spatial light modulator, SLH, L7 — photodetector, PC-computer.

In the figure, we see a good agreement between theory (a) and experiment (b). Intensity patterns when propagating from Z = 0 to Z = 10 do not change even in the perturbed region, in other words, the beam remains structurally stable.

Why the SB keeps stability without changing its perturbed structure despite removing several optical vortices and breaking partially the clusters? Our task is to trace the main features of the perturbed energy flow for the angle of attack of the sector perturbation, and to reveal our interest in their structural stability. In the center of figure there is a streamlines pattern of the sector perturbation cross section against a background of the flux density. Despite it breaks down the circular flow, forms new vortices at the vertex of the triangle and the modes in the beams axis, does not significantly change the inner structure of the streamlines. In the vicinity of the vertex, three remains of the vortex are formed, separated from each other and the inner region of the sector by two separations, streamlines circulate around the critical points with opposite signs. The increased perturbation "streamers" vortices from distorted regions to the corner region.

We have deliberately expanded the range of perturbation angles in order to reveal the perturbation region where vortices with negative TC have a significant effect. In the full angular range the informational entropy (b) slowly increases, since the contribution of new LG states to the perturbed beam is increases. The OAM (a) remains unchanged over almost the entire range of perturbation angles, and only when the beam is practically overlapped does the OAM decrease to zero.

Conclusion

We have experimentally confirmed that the OA beam remains stable under the influence of perturbations, and the orbital angular momentum (OAM) of the beam remains constant even when the beam is distorted by the perturbation. This finding has important implications for the design and application of OA beams in various fields such as optical communications, microscopy, and holography. The stability of OA beams in perturbations could enable new applications in these fields, potentially leading to improvements in the efficiency and precision of optical systems. Further research could explore the implications of these findings for the development of new optical technologies and the optimization of OA beam usage in practical scenarios.