Inverted Field Interferometer for Measuring the Topological Charge of Optical Vortices

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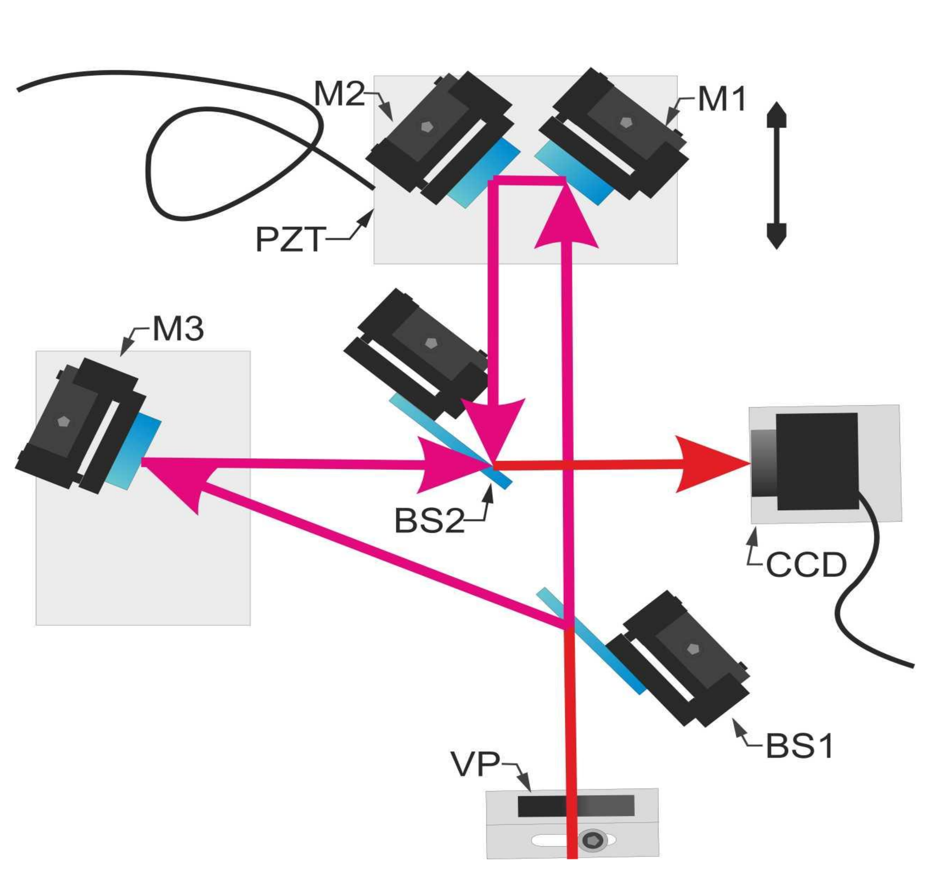
INTRODUCTION

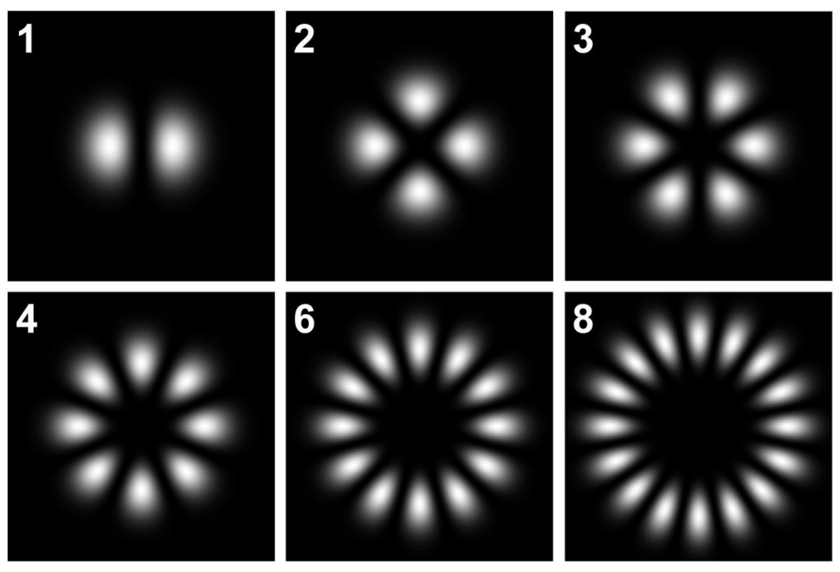
We present a technique for measuring both the magnitude and sign of the topological charge (TC) of optical vortex beams. The method itself relays on well aligned collinear inverted field interferometer (IFI) setup. IFI differs from usual interferometers in the number of reflections in their arms prior to the final overlap of the beams [1]. Then, as a result of an additional reflection in one of the arms, the two interfering beams propagate collinearly with one of the beams being flipped with respect to the second one. Letting a vortex beam with an unknown TC to pass through it, one can observe/record an interference pattern resembling the so called "necklace beam" [2,3] profile. As a first step, the modulus of the TC can be determined by counting the number of observed pattern peaks, which corresponds to the double of the absolute value of input beam TC. As a second step, the time delay in the interferometer can be changed causing rotation of the interference peaks. When using calibrated IFI, the direction of this rotation determines the sign of the TC of the OV. Simulations, based on analytical model, and experimental evidences for the interference signal obtainable at the output of IFI are in an excellent agreement. These results are valid for both continuous wave and femtosecond optical vortex beams and pulses with an eventual pulse front tilt [1,4]. An IFI also appears to be a valuable tool for calibrating a built-in variable delay line and for estimating an eventual pulse front tilt of the input ultrashort laser pulses without any realignment.

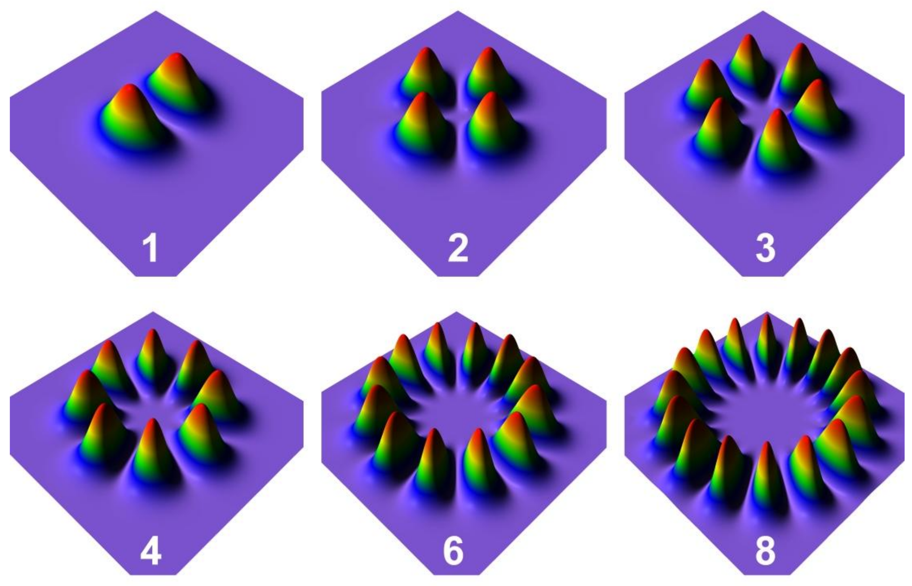
IFI SETUP



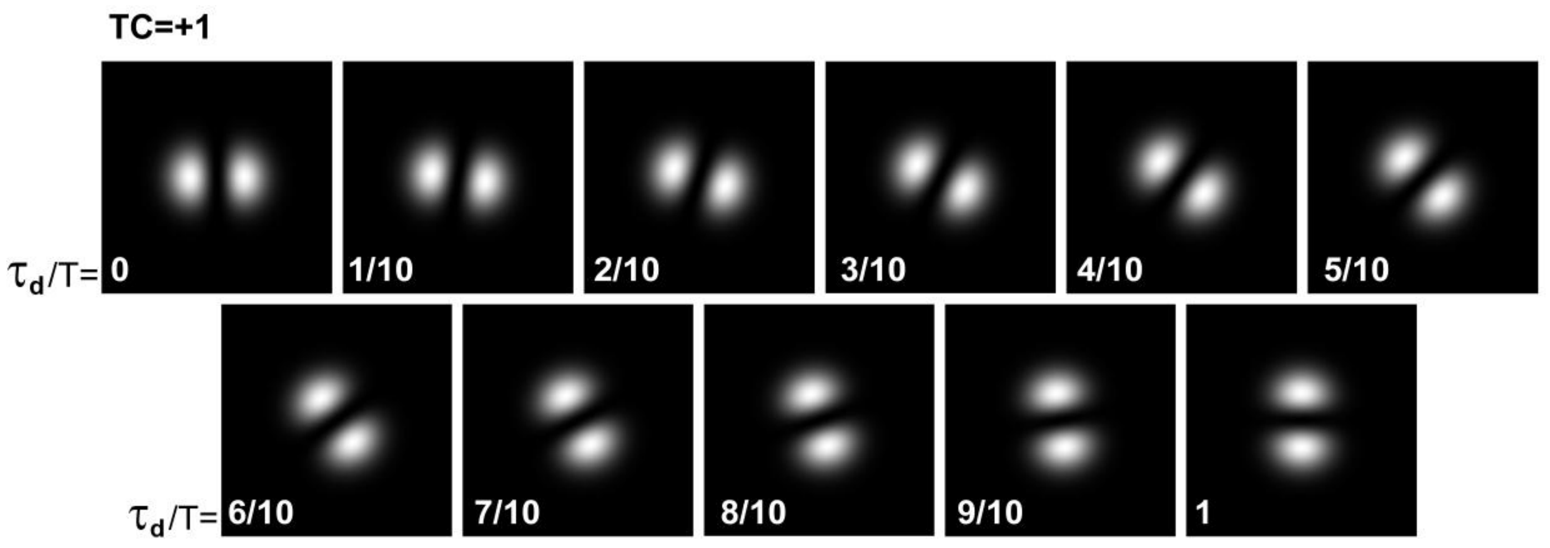
NUMERIC RESULTS

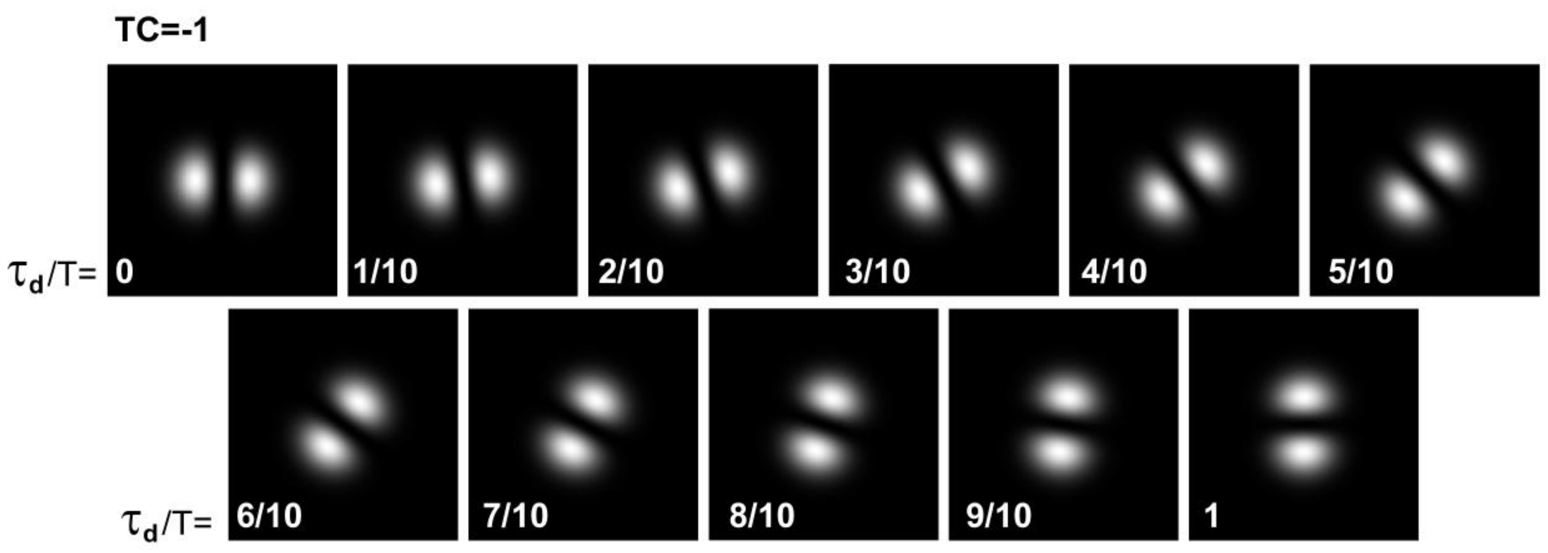
1. Energy distribution pattern at the output of the IFI. In case of optical pulses the results are valid provided the temporal delay between them is $\tau = 0$.





2. Energy distribution pattern at the output when varying the delay between the pulses in the arms of the interferometer.





THEORETICAL MODEL

In each of the two IFI arm, we have optical pulse/beam field described as:

$$E_1(x,y,t,m,\alpha) = \left(\mathrm{r}\sqrt{2}/\mathrm{r}_0\right)^{|\mathrm{m}|} \mathrm{e}^{-\left[\frac{t^2}{\mathrm{t}_0^2}\right]} \mathrm{e}^{-\left(\frac{r^2}{\mathrm{r}_0^2}\right)} \mathrm{e}^{\mathrm{i}(\omega_0 t \pm |\mathrm{m}|\varphi)}$$

$$E_2(x,y,t-\tau_d,m,-\alpha) = \left(\mathrm{r}\sqrt{2}/\mathrm{r}_0\right)^{|\mathrm{m}|} \mathrm{e}^{-\left[\frac{(t-\tau_d)^2}{\mathrm{t}_0^2}\right]} \mathrm{e}^{-\left(\frac{r^2}{\mathrm{r}_0^2}\right)} \mathrm{e}^{\mathrm{i}[(t-\tau_d)\omega_0 \mp |\mathrm{m}|]}$$

For the time-integrated interference signal S to be recorded by the CCD-camera of the IFI operated with vortex beams we obtained the following result:

$$S(x,y,m,\tau_d) = \int_{-\infty}^{+\infty} |E_1(x,y,t,m) + E_2(x,y,t-\tau_d,m)|^2 dt$$

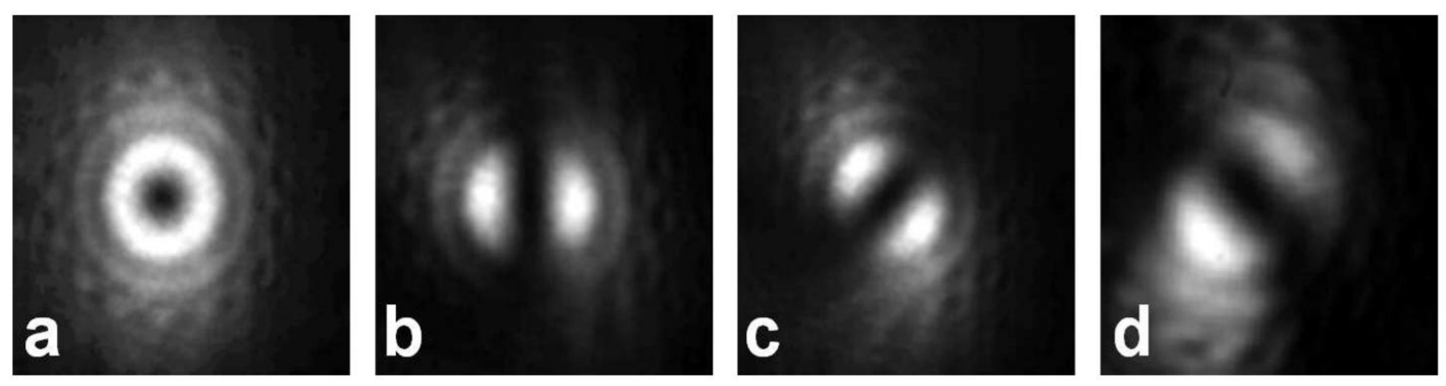
$$= S_0(\mathrm{r}/\mathrm{r}_0)^{2|m|} e^{-2\left(\frac{r^2}{\mathrm{r}_0^2}+\frac{\tau_d{}^2}{\mathrm{t}_0^2}\right)} \left(e^{\frac{2\tau_d{}^2}{\mathrm{t}_0^2}} + e^{\frac{3\tau_d{}^2}{2\mathrm{t}_0^2}} \cos[\tau_d\omega_0 \pm 2|\mathrm{m}|\varphi]\right)$$

where:

$S_0 = 2^{|m|}\sqrt{2\pi}\mathrm{t}_0$.

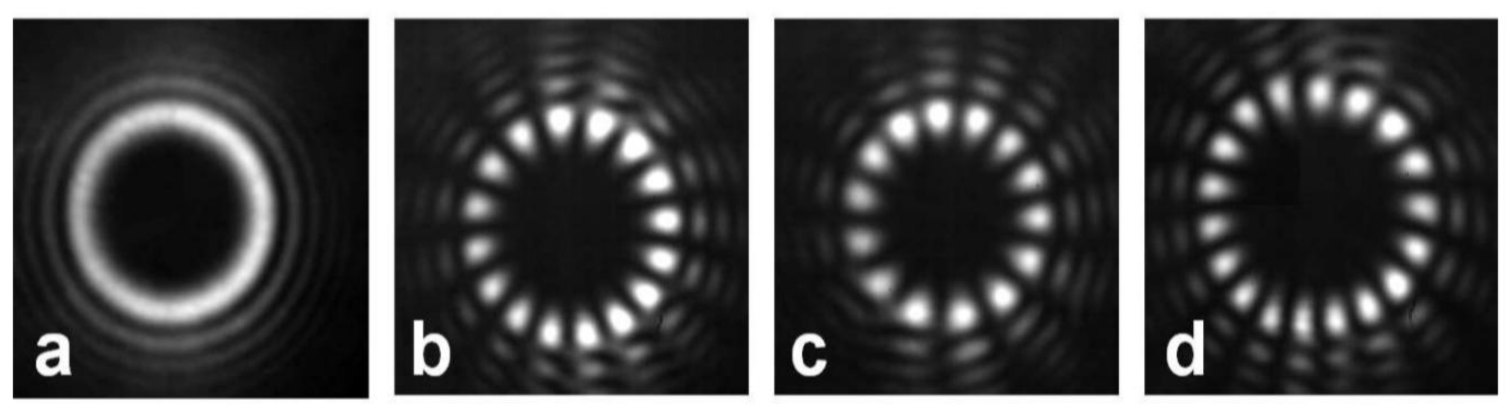
EXPERIMENTAL RESULTS

1. CCD camera images recorded at the output of the IF interferometer when the vortex TC is set to one:



a) Large temporal delay – no interference;
b) no delay – fully overlapping pulses;
c) small positive delay - smaller than the pulse temporal duration ($\tau d = 7$fs, corresponding to rotation angle of 3 ×180deg.);
d) the same negative delay.

2. Recorded images for different input vortex beam TCs:



a) TC=+8 and large delay between two pulses;
b) TC=+8 and perfect temporal pulses overlapping;
c) TC=+7 and perfect temporal pulses overlapping;
c) TC=+9 and perfect temporal pulses overlapping.

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REFERENCES

[1] N. Dimitrov, L. Stoyanov, I.Stefanov, A. Dreischuh, P. Hansinger, G.G. Paulus, Optics Communications, pp. 51-58, vol. 371 (2016).
[2] M. Soljacic, S. Sears, and M. Segev, Phys. Rev. Lett., pp. 4851–4854, vol. 81 (1998).
[3] L. Stoyanov, N. Dimitrov, I. Stefanov, D. N. Neshev, A. Dreischuh, J. Opt. Soc. Am. B, pp. 801-807, vol. 34 (2017).
[4] N. Dimitrov, L. Stoyanov, I. Stefanov, I. P. Christov, A. Dreischuh, Bulg. J. of Physics, pp. 99-108, vol. 44 (2017).

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