Acoustic and Optic drills by dynamic high-order Bessel beam mixing

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Abstract: We demonstrate experimentally dynamical acoustic and optical "drill" beams, presenting nonstationary intensity distributions that resemble the spinning mechanical drill. The drills appear as the spatiotemporal interference of two Bessel-vortex beams of different topological charges and different carrier frequencies. We explore material processing with such drills.

Exotic beams such acoustic vortices are emerging as tools for wave-matter interaction, including particle trapping and manipulation, mechanical torque transfer applications, or acoustic transceivers and underwater communications. Acoustic vortex beams are wave fields with phase singularities, and around these spots the phase of the beam rotates with the azimuthal coordinate. Therefore, in acoustic beams the phase is helical in the space. In this work we present acoustic drills, a new type of beam whose intensity distribution matches the shape of a helix, twisting around the beam axis. In addition, the intensity distribution rotates with time along the axis of the beam with a controlled direction and angular frequency, therefore resembling the shape of a rotating mechanical drill [1]. The acoustic drill which we present here is analogous to the recently demonstrated optical drill [2].

We synthesize two confocal and detuned Bessel beams of elongated focal spot and arbitrary topological charge using two concentric 3D-printed acoustic holograms. The outer beam is excited by a custom piezoelectric ring (84-mm external diameter, 50-mm internal diameter) and a concentric unfocused circular transducer (50-mm aperture). Each transducer is excited with a separate AWG and RF amplifier, with a pulsed burst of around 1 MHz central frequency. The frequency was slightly detuned, to about several Hertz. Field measurements were taken in water, k-space pseudospectral simulations were performed, and the field was calculated using the Rayleigh-Sommerfeld integral. Camera measurements were taken at the surface of the water.

We show that elongated drill beams are obtained using two high-order Bessel beams. Analytic, numeric, and experimental results are in good agreement, showing the helical structure of intensity distribution rotating with a controlled angular frequency. Acoustic drills emerge as the spatiotemporal interference of two confocal and detuned vortex beams. Analytical constraints for optimal beam overlapping were obtained. We show how the parameters of the helical beam are fully tuneable, their period, winding, rotation speed and direction, number of windings, and we link these parameters to the geometrical and detuning parameters of the primary vortex beams. This new wave structure opens novel avenues for wave-matter interaction, such as contactless particle manipulation, matter processing or biomedical applications.

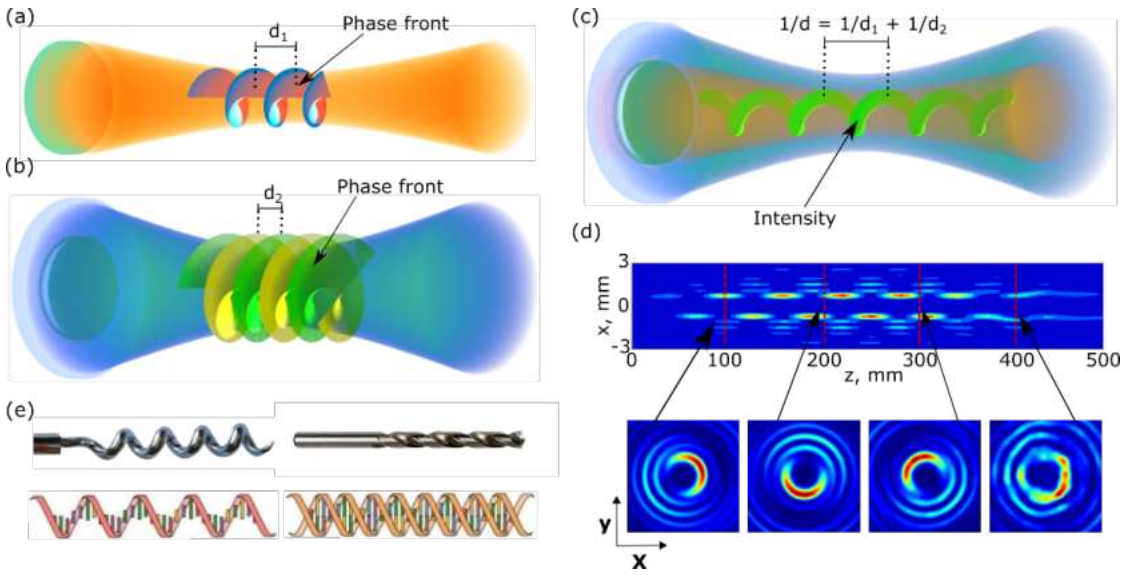


Fig.1. Acoustic drill beams. (a) phase helical Bessel beam with the single helicity m=1; (b) phase helical Bessel beam with the double helicity m=2; (c) Optical drill bit emerging from the interference of phase-helical beams (a) and (b); (d) axial x-z and transverse x-y cross-sections of the simulated intensity distribution; (e) mechanical and biological analogues of the same geometrical structure.

References

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