Generating focused vortex beams using chiral reflectors

Background, Motivation and Objective

Vortex beams are currently used in many emerging therapeutical ultrasound applications. There exist many methods to synthesize intense vortex beams, including piezoelectric phased-array transducers, helical radiating surfaces, passive structures such as reflective lenses and holograms, diffractive systems such as active and passive spiraling diffraction gratings, or lenses using inner resonances. However, many of these methods cannot be applied in reflection mode, to focus intense acoustic wavefronts and generate acoustic vortices. In this work, we present several reflectors topologies to synthesize focused vortex beams for therapeutical ultrasound.

Statement of Contribution/Methods

We present the design equations, the numerical and experimental validation of several topologies of reflectors used to generate focused vortex beams. By using geometrical methods, we derived the parametric surfaces for helico-elliptical vortex reflectors to be used with electrohydraulic sources, and an helico-parabolical vortex reflector to be used with cylindrical electromagnetic sources. The pressure gain, focal dimension and topological charge of the different vortex generators is explored and linked to the geometrical parameters. The performance of these topologies is validated experimentally in a water tank using a fiber-optic hydrophone and holographic projection techniques and compared with pseudo-spectral time-domain simulations.

Results/Discussion

Results show that both reflector topologies, helico-elliptical reflectors and helico-parabolic reflectors, can generate focused acoustic vortex beams containing phase dislocations. By tuning the design equations, the topological charge of the vortices can be selected. Vortices with integer topological charge emerge at the design frequency and at multiples of the design frequency. However, we observe vortices of fractional topological charge at other frequencies due to incomplete phase loops. In this way, while these structures can focus broadband acoustic beams, phase dislocations of integer topological charge cannot be generated at low frequency, i.e., reflected pulses corresponds to vortices of fractional topological charge. Helico-elliptical and helico-parabolic reflectors efficiently generate focused vortices. While these complex wavefronts can be generated by phased-arrays or lenses, the proposed chiral mirrors do not introduce remarkable attenuation and they can be used in combination with electrohydraulic and electromagnetic sources. Therefore, they are suitable to manipulate wavefronts with large mechanical amplitude, such as those used in lithotripsy, histotripsy, or other particle and tissue manipulation applications.

