Nonlinear focal shift in medium Fresnel-number focused acoustic beams

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Abstract

○ Focused Ultrasound beams are an active field of research as they are relevant in most of the ultrasonic applications in medicine and industry.

○ The Linear focal shift was explained by Lucas & Muir in 1982.

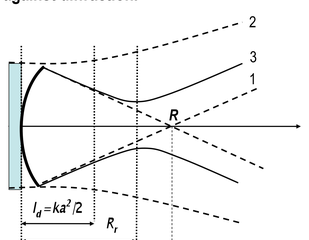
○ The Nonlinear focal shift has been also reported in previous works along the past decades.

○ A Medium Fresnel number transducer, N_F=6 and f-number=6.3 has been studied numerically and experimentally, and the Linear and Nonlinear focal shifts are reported for this transducer.

○ We demonstrate that the nonlinear focal shift is able to move the on axis maximum pressure location beyond the geometrical focus of the transducer.

The Linear focal shift

Focusing against diffraction.



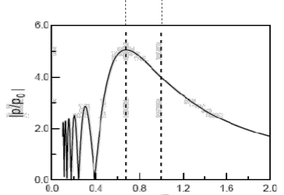


Fig. 1 Transversal and axial representation of the acoustic field generated by a focused transducer.

The Fresnel number

Beyond geometrical considerations in the concept of focusing.

$$N_F = \frac{AA'}{\lambda/2} = \frac{R - \sqrt{R^2 - a^2}}{\lambda/2} \approx \frac{a^2/2R}{\lambda/2} = \frac{a^2}{\lambda R}$$

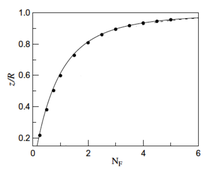


Fig. 2 Linear focal shift for different Fresnel number transducers.

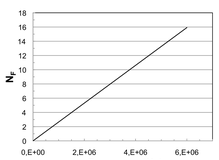


Fig. 3 Dependency of the Fresnel number with the frequency. f-number = 6.3

Experimental set up and procedure

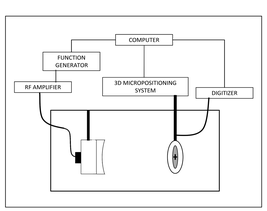


Fig. 4 Experimental design.

-Function Generator: PXI5412, 14 bits, 100 MS/s, NI.

-RF Amplifier: ENI 1040L, 400W,+55 dB.

-Digitizer: PXI5620, 64 MS/s, NI.

-Micropositioning System: OWIS GmbH (Acuracy 10 µm)

-Water Tank: (60x40x38 cm).

-TRANSMITTER: PZ26 + lens
- f_0= 2.227 MHZ
- **2a**= 50 mm
- **F**=157 mm

f-number = 6.3 → N_F=6

(Geometrical Focal length)

-RECEIVER: Membrane Hidrophone (MH2000B, NTR/ Onda Corp, 200µm active diameter)

Measurement procedure

Acoustic waveforms were evaluated at 25 transversal planes (6x6mm) through the transmitter axis with 0.25 mm *x-y* spatial resolution. 1 mm *z*-separation between the planes in the focus region.

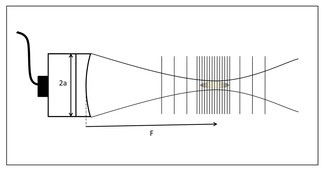


Fig. 5 Distribution of the 25 transversal planes during the experiment.

Linear characterization of the beam

The characterization of the beam in linear regimen allows us to know the characteristics of our acoustic source (aperture and geometrical focus) and is the starting point for the analysis of the nonlinear behaviour.

	Geometrical Focal (mm)	Aperture (mm)
Nominal values	157.0	25.0
O'Neil	158.2	25.8
KZK simulation	157.0	25,1

Table 1. Characteristics of the acoustic source.

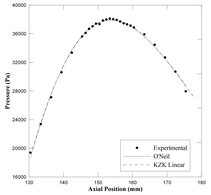


Fig. 6 On axis pressure distribution. Experimental values, analytical O'Neil expression and KZK simulation.

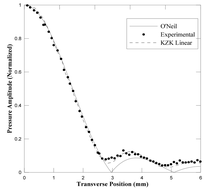


Fig. 7 Transversal normalized pressure at the focus. Experimental values, analytical O'Neil expression and KZK simulation.

The nonlinear focal shift

The *nonlinear focal shift*, i.e. the displacement of the pressure and intensity maxima position of focused acoustic beams under increasing driving voltages, has been previously observed numerically and experimentally.

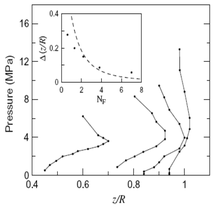


Fig. 8 KZK simulations for different transducers [12, 14, 15].

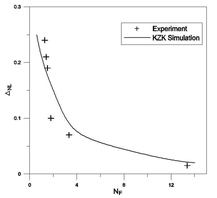
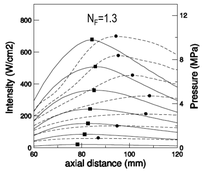


Fig. 9 Historical evidences of the nonlinear focal shift for different transducers [8-12].



TRANSMITTER: *Valpey-Fisher*

f-number = 7.8 →
- f_0= 1.1 MHz
- **2a**= 25 mm
- **F**=117 m

(Geometrical Focal length)

N_F=1.3

Fig. 10 Nonlinear focal shift on the on axis maximum pressure and intensity. Experimental values from [12]. Input values are from 200 to 500 V_{pp} from bottom to the top.

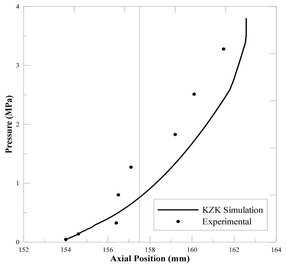


Fig. 11 Nonlinear focal shift on the on axis maximum pressure. Experimental and numerical values for a N_F=6 transducer. Input values are from 2 to 125 V_{pp} from bottom to the top.

Beyond the geometrical focus

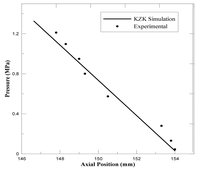


Fig. 12 Nonlinear focal shift on the on axis minimum pressure.

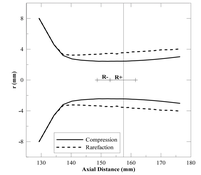


Fig. 13 Half amplitude beam shapes, for positive and neative pressures (dashed). R+ y R- denote the movement range of maximun and minimun pressure respectively

Acknowledgements

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