MINIATURIZED ACOUSTIC CONCENTRATORS FOR LOCAL GENERATION OF ULTRASONIC WAVES

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1 Introduction

3D ultrasound imaging is an essential medical imaging technique used for diagnosing and monitoring diseases. It is based on the use of ultrasonic waves to create real-time, non-invasive images of soft tissues [1]. To form these images, virtual sources are usually used as emitters, enabling the creation of diverging or planar ultrasonic beams from different virtual positions. This approach offers greater flexibility in exploring the region of interest and reach high frame rates up to 10 kHz [1]. Research has been conducted to optimize the use of these virtual sources and improve the quality of the obtained images [2]. However, there are challenges related to a low sensitivity of the virtual sources, their positioning, and the complexity of multiplexing. To overcome these obstacles, the use of miniaturized concentrators based on cylindrical waveguides is emerging as a promising solution. The approach adopted is described in Figure 1 and opens up new possibilities in the field of 3D ultrafast imaging.

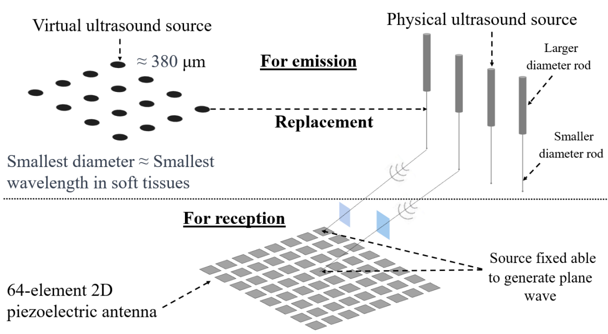

Figure 1: Transition from virtual ultrasound sources to physical ultrasound sources based on waveguides for ultrafast 3D imaging.

2 Transmission and Reflection in Axisymmetric Waveguides

2.1 Propagation of Axisymmetric Longitudinal Waves in a Cylindrical Waveguide

The propagation of axisymmetric longitudinal waves in a cylindrical rod with a uniform cross-section are theoretically described by the Pochhammer-Chree equations [3]. The elastic properties of the rod are taken into account. The frequencies of interest for this study range from 20 kHz to 2 MHz. The axisymmetric longitudinal modes are characterized by the radial displacement (u) and axial displacement (w) in the cylinder. Eq.1 describes the relationship between the wavenumbers (k and q) and the frequency (f) of the axisymmetric longitudinal modes in the cylinder.

$$\frac{2p}{a}(q^2+k^2)J_1(pa)J_1(qa)-(q^2-k^2)^2J_0(pa)J_1(qa)...$$
$$-4k^2pqJ_1(pa)J_0(qa)=0 \quad (1)$$

Where a represents the radius for a given rod, p and q are related to the wavenumber. This dispersion curve $k(f)$ is obtained by numerically solving the Pochhammer-Chree equation and allows the determination of the allowed propagation modes in the cylindrical rod.

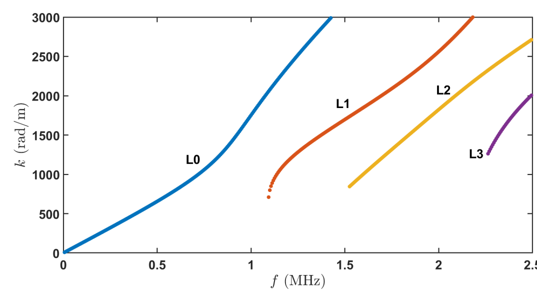

Figure 2: Dispersion curve of axisymmetric longitudinal modes in the rod: wavenumber (k) as a function of frequency (f).

2.2 Transmission and Reflection of Axisymmetric Longitudinal Waves in a Variable Cross-Section Guide

The propagation of modes in a waveguide with a variable cross-section is illustrated by the diagram in Figure 3. This guide allows the transmission of a mode from a large-diameter cylindrical rod (D_1) to a small-diameter cylindrical rod (D_2). The study is conducted in the frequency domain by considering a 2D axisymmetric FEM model in COMSOL Multiphysics 6.0 with MATLAB. The model parameters, such as the material (stainless steel), waveguide length, maximum phase velocity, maximum and minimum wavelengths, as well as the PML length and mesh element size are taken into account. The modes are normalized with respect to the incident energy to determine the transmission and reflection coefficients.

2.3 Numerical Results

At $f = 1$ MHz, only the L0 mode propagates effectively in the guide. For low diameter ratios $D_2/D_1 < 0.75$, the

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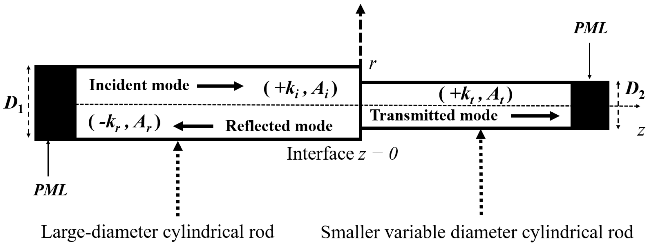

Figure 3: Transmission of a mode in a guide with a variable cross-section.

energy transmission is below 80 %. However, for ratios $D_2/D_1 \geq 0.75$, the energy transmission is complete. This relationship between the diameter ratio and energy transmission is illustrated in Figure 4. This analysis demonstrates the

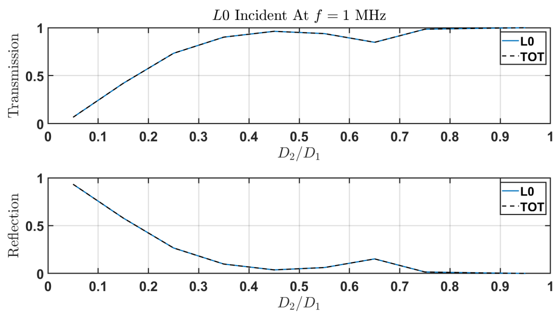

Figure 4: Energy transmission and reflection for the incidence of an L0 propagating mode at a frequency of 1 MHz as a function of the diameter ratio D_2/D_1 between the reducer and the base waveguide.

influence of the diameter ratio on energy transmission and reflection in a variable cross-section waveguide, highlighting the conditions favorable for efficient transmission of ultrasonic waves.

3 Preliminary Experimental Study

The experimental setup used is illustrated in Figure 5. In this

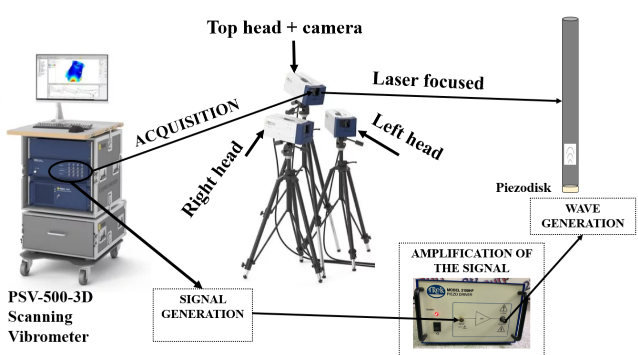

Figure 5: Experimental setup.

experiment, a 3D laser vibrometer is used to measure the vibrations of the cylindrical rod. The generation of ultrasound is performed using a 5A-type piezodisk, with a diameter of 5 mm and a thickness of 0.5 mm. For vibration measurements, a single 3D laser Doppler vibrometer head is used, consisting of an upper head and a camera. A stainless steel cylindrical rod is used. It has a length of 1.2 m and a diameter of 6.3 mm. The piezodisk is attached to the base of the rod using epoxy glue. A pseudo-random input signal amplified with a piezo amplifier is used to excite the piezodisk. Post-processing of the data is performed using a 2D FFT method to convert from the spatial domain (x, t) to the wavenumber-frequency domain (k, f). Figure 6 shows the longitudinal and flexural modes that propagate in the guide. The matrix pencil method is then used to extract only the longitudinal modes, characterized by their amplitudes and wavenumbers.

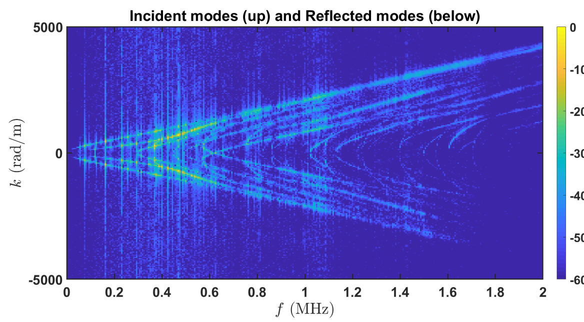

Figure 6: Incident and reflected modes obtained experimentally using 2D FFT for the steel rod.

4 Conclusions

Numerical simulations were used to determine the optimal diameters of a reducer (D_2) used in the imaging domain. The performance of the reducer was evaluated through preliminary simulations, which selected a minimum diameter of 0.381 mm to ensure efficient operation. In parallel, experimental results obtained using a 3D LDV will be used as a reference to measure the longitudinal modes in different variable cross-section guide models. The goal is to detect and characterize these modes. These two types of results, from numerical simulations and experiments, play an essential role in understanding the performance and characteristics of reducers and variable cross-section guides. They will serve as a basis for future studies, improvement of designs, and exploration of new applications in the fields of imaging and acoustic technologies.

References

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