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# Beam Profile Characterization for Thickness Mode Transducers versus Radial Modes

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*Abstract*— **In this work, previous work performed in our team that established the viability of using radial clamping on piezoelectric discs operating on their radial mode resonant frequencies to produce a collimated, yet low-frequency ultrasonic beam is expanded to test commercial viability by comparing against high quality, commercially available thickness mode transducers. A concern that is brought against the competitiveness of using the radially clamped transducer for collimated, low-frequency operation is that a higher quality substitute is available in the form of a thickness mode transducer with a piston mode frequency matching that of the radially clamped radial mode transducer. This work aims to show the advantages of radially clamped radial mode transducers versus thickness mode transducers of the same frequency. In particular, it was found that although the thickness mode transducers generated larger main lobe energies at close distances, they suffered from larger dispersion at longer distances. The radial mode transducers were capable of maintaining a very narrow beam throughout the entire measurement range (one meter), demonstrating superior performance for long range applications. Both transducers, however, performed far better than a free boundary radial mode transducer, which shows that if radial mode operation is to be used, radial clamping is a necessity.**

***Keywords—Ultrasonic Transducers, Beam Profiles, Collimation***

## I. Introduction

Today, many important industries and applications rely on high-resolution ultrasonic imaging and beam projection for success. Some of these applications include borehole inspection, underwater communication, medical screenings, and many others. Generally, to achieve high resolution images using ultrasound, higher frequencies are used up to the resolution that is required. Unfortunately, although this works for some scenarios, higher frequencies suffer from increased attenuation which can render it useless when the imaging media has high attenuation properties or the desired projection distance is very long. In these cases, lower frequency ultrasound could be used to increase penetration depth, but such ultrasound suffers from very poor collimation and high angular spread, which makes precision imaging and projection near impossible. Previously in our group, however, we have shown the ability to overcome these limitations and produce highly collimated, low frequency ultrasound with high side lobe suppression by radially clamping a piezoelectric disc and operating the disc on its radial modes [1-3]. This redirects the energy away from the side lobes and into the main lobe, increasing both the degree of collimation and the total amount of energy outputted into the main lobe. Despite this advance, it is still important to note that such an advancement would be of limited utility if transducers operating in their thickness mode with identical center frequencies to the clamped radial mode transducers could produce beam profiles with high collimation. This is due to the superior conversion efficiency of thickness mode operation versus radial modes. In this work, it is demonstrated that clamped radial mode piezoelectric transducers have better collimation and longer operation range, while being flexible enough to operate at multiple frequencies (due to there being multiple radial modes) instead of just a single frequency.

## II. Experimental

Both transducers that were used in this study were sourced from Boston PiezoOptics. The first transducer, which was first characterized unaltered, and then radially clamped by bonding it to a Plexiglas ring using a Tungsten epoxy, was a 1 MHz center frequency Lead-Zirconate-Titanate 5A (PZT-5A) 25.4 mm diameter piezoelectric disc, with a thickness of 2.1 mm. The second transducer, which was operated on its piston mode (or thickness mode) had the same diameter, but a thickness of 9.1 mm. The center frequency of the thickness mode transducer was matching that of the fourth radial mode of the first transducer (215 kHz). The transducers were excited using an arbitrary function generator (AFG), Tektronix model 3102, with a finite length train of pulses of fixed frequency (fixed-frequency Tukey Envelope). The resonant modes were identified experimentally through the impedance spectrum obtain from a Bode 100 vector

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network analyzer. A Teledyne Reson model TC4013 hydrophone was used as receiver. The receiver was stepped through a large water tank using a Velmex precision 3-axis stage system while the transducer used as an acoustic source was held fixed on one end. The received pulse was routed through a Keithley model 3940 digital programmable filter set to band pass the signal between 10-300 kHz (Butterworth) and apply a 40 dB output gain. The signal is then digitized by a Tektronix model 7054 Digital Phosphor Oscilloscope (DPO) which is triggered by the AFG. A Visual Basic code controlled the AFG output, DPO, stepper motor position, and digitization of the filtered signal. The DPO programmatically gated the received signal around the expected first arrival time, thus only measuring the received amplitude of the primary and none of the secondary arrivals from reflections in the tank. Using the amplitude of the primary, along with the position of the hydrophone at each point, a 2D beam profile was created. Since the transducer is axisymmetric, the 2D profile can be rotated around the propagation axis to obtain a 3D beam profile. The surface of the piezoelectric transducers was scanned with a Scanning Laser Doppler Vibrometer before experiments to ensure no manufacturing defects were present that would break the symmetry.

## III. Results and Discussion

The beam profile for the PZT-5A 1 MHz piezoelectric transducer, excited at its 4th radial mode, 215 kHz, is shown below in Fig. 1.

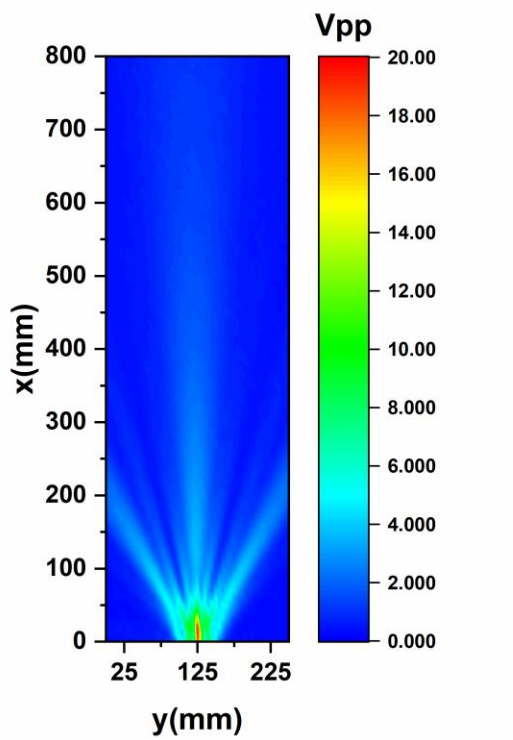


Fig 1. Beam profile for the free radial mode transducer

The number of side lobes is in line with it being the fourth radial mode. Additionally, as this transducer is unaltered (no backing, free boundary conditions), the energy projected through the side lobes is significant. Fig 2. shows the same exact transducer, but after radially clamping it around its circumference. This was achieved by bonding the edge of the transducer to a Plexiglas ring using Tungsten epoxy.

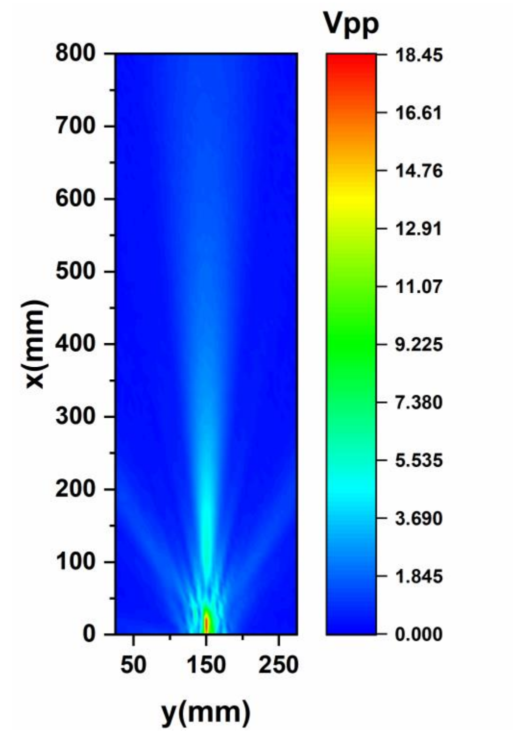


Fig 2. Beam profile for the clamped radial mode transducer

In this case, the clamping has redirected a significant amount of energy that was originally in the side lobes to the main lobe, increasing the beam range. The main lobe is also significantly collimated, having a very low divergence over the length of the water tank. Finally, Fig 3. shows the beam profile of a separate piezoelectric transducer operating at its thickness mode, 218 kHz.

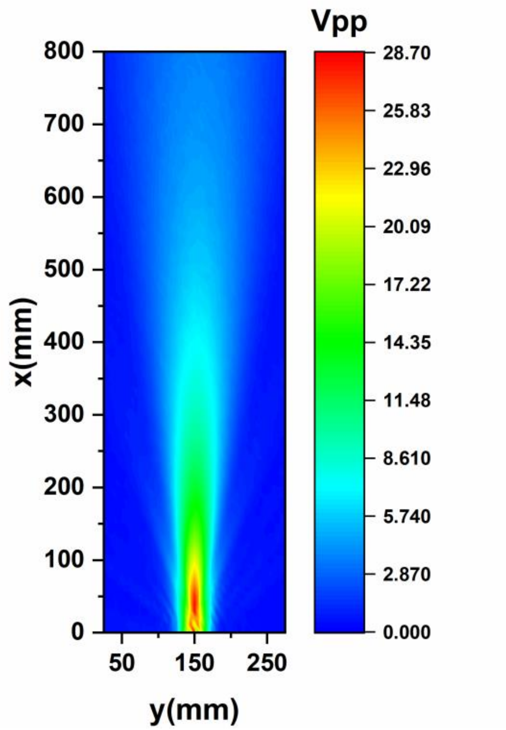


Fig 3. Beam profile for the thickness mode transducer

As expected, operating a transducer at the thickness mode produces a much stronger signal. However, unlike the clamped transducer, this transducer shows poorer collimation as compared with the radial mode transducer. This demonstrates that the clamped radial mode transducer is a better candidate for high resolution imaging applications, or any other applications that require high collimation but low frequency.

## IV. CONCLUSIONS

In this work, the viability of using a clamped radial mode transducer was explored. When compared to the free piezoelectric transducer, the clamped transducer had significant side lobe reduction, as well as increased main lobe power. Compared to the thickness mode transducer, the clamped radial mode transducer had much better collimation at all studied distances, but the thickness mode transducer had very little side lobes. While there are certain applications where a thickness mode transducer would be preferable, such as when high power is required over a short distance, it was determined that the clamped radial mode transducer is better for most applications, including high resolution imaging through highly attenuating media.

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