Calibration of Air-Coupled Transducers for Absolute Nonlinear Ultrasonic Measurements

Nicholas Selby[1], Undergraduate Research Assistant

David Torello[1], Jin-Yeon Kim[2], Laurence J. Jacobs[1,2]

[1]G.W. Woodruff School of Mechanical Engineering, Georgia Institute of Technology, Atlanta, GA, 30332

[2]School of Civil and Environmental Engineering, Georgia Institute of Technology, Atlanta, GA, 30332

Motivation

Absolute Nonlinear Ultrasonics (NLU)

- Absolute NLU has the potential to **detect material degradation** and provide quantitative information about substructural changes in a material

- Current noncontact measurement techniques are **relative**. They can only be used if the complete history of the specimen **is already known**
- **Absolute** measurement techniques can determine nonlinear material parameters for materials with no measurement history

Air-Coupled Transduction

- Air-coupled transducers are preferable for their **low cost and greater robustness** over other receiver technologies due to lack of dependence on contact and surface conditions
- Air-coupled transducers must be **calibrated** in order to provide absolute measurement data
- Standard pulse-echo (self-reciprocity) calibration doesn't work because of low power output from the transducer

Objectives

- **Calibrate** an air-coupled transducer by experimentally identifying its force/voltage transfer function with a model-based, pitch-catch experimental configuration
- **Confirm** calibration with laser interferometer measurements of excited material surface

Theoretical Background and Methods

Second Harmonic Generation

- **Material nonlinearity** is measured when material defects and microstructural effects cause a monochromatic wave to **distort** into a **fundamental (ω)** and **second harmonic (2ω)** component
- For longitudinal waves, material nonlinearity is denoted by **β** and adheres to the relationship:

$$\beta = \frac{8A_2}{A_1^2 k^2 x}$$

A_1 and A_2 denote absolute amplitudes of fundamental and first harmonic wave frequency components

Multiple Gaussian Beam Modelling

- Computationally efficient method to model longitudinal wave propagation
- Source velocity expressed as sum of Gaussians, which **propagate as Gaussians**:

$$V_0(\xi) = \sum_{n=1}^{N=15} \boldsymbol{A_n} \exp\left(-\frac{\boldsymbol{B_n} r^2}{a^2}\right)$$

- **Source velocity is translated to pressure** via the following relationships:

$$\tilde{p}_1(z) = [p_0 \exp(ikz)][\boldsymbol{M_1(\alpha_1, z)}][\boldsymbol{D_1(a, f, z)}]$$

$$\boldsymbol{M_1(\alpha_1, z)} = e^{-\alpha_1 z}$$

$$\boldsymbol{D_1(a, f, z)} = \sum_{m=1}^{N} \frac{A_m}{1 + iB_m z/D_R} \exp\left(\frac{i\omega}{2} \frac{iB_m/c_0 D_R}{1 + iB_m z/D_R} r^2\right)$$

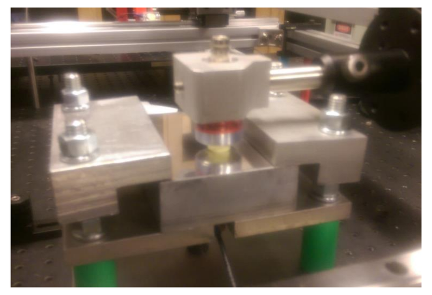
$$\tilde{p}_2(z) = \left[\frac{\beta k z}{2\rho_0 c_0^2} p_0^2 \exp(2ikz)\right][\boldsymbol{M_2(\alpha_1, \alpha_2, z)}][\boldsymbol{D_2(a, 2f, z)}]$$

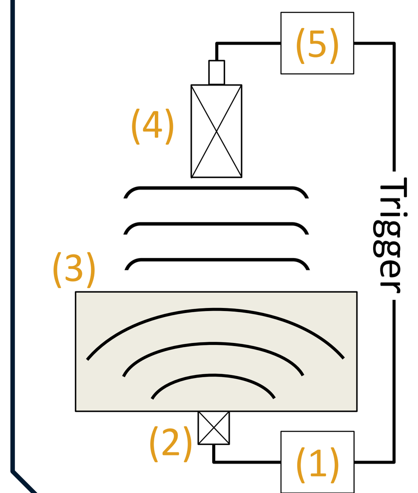
$$\boldsymbol{M_2(\alpha_1, \alpha_2, z)} = \frac{e^{-2\alpha_1 z} - e^{-\alpha_2 z}}{(\alpha_2 - 2\alpha_1)z}$$

$$\boldsymbol{D_2(a, 2f, z)} = \frac{1}{z}\int_0^z \sum_{n=1}^{N}\sum_{m=1}^{N} \frac{2A_n A_m}{(2 + B_a z) + (B_a - 2B_b z)z'} \exp\left(\frac{ikr^2(B_a - 2B_b z')}{(2 + B_a z) + (B_a - 2B_b z)z'}\right) dz'$$

- Pressure is then integrated over transducer surface to calculate **received force for calibration**

Experimental Setup

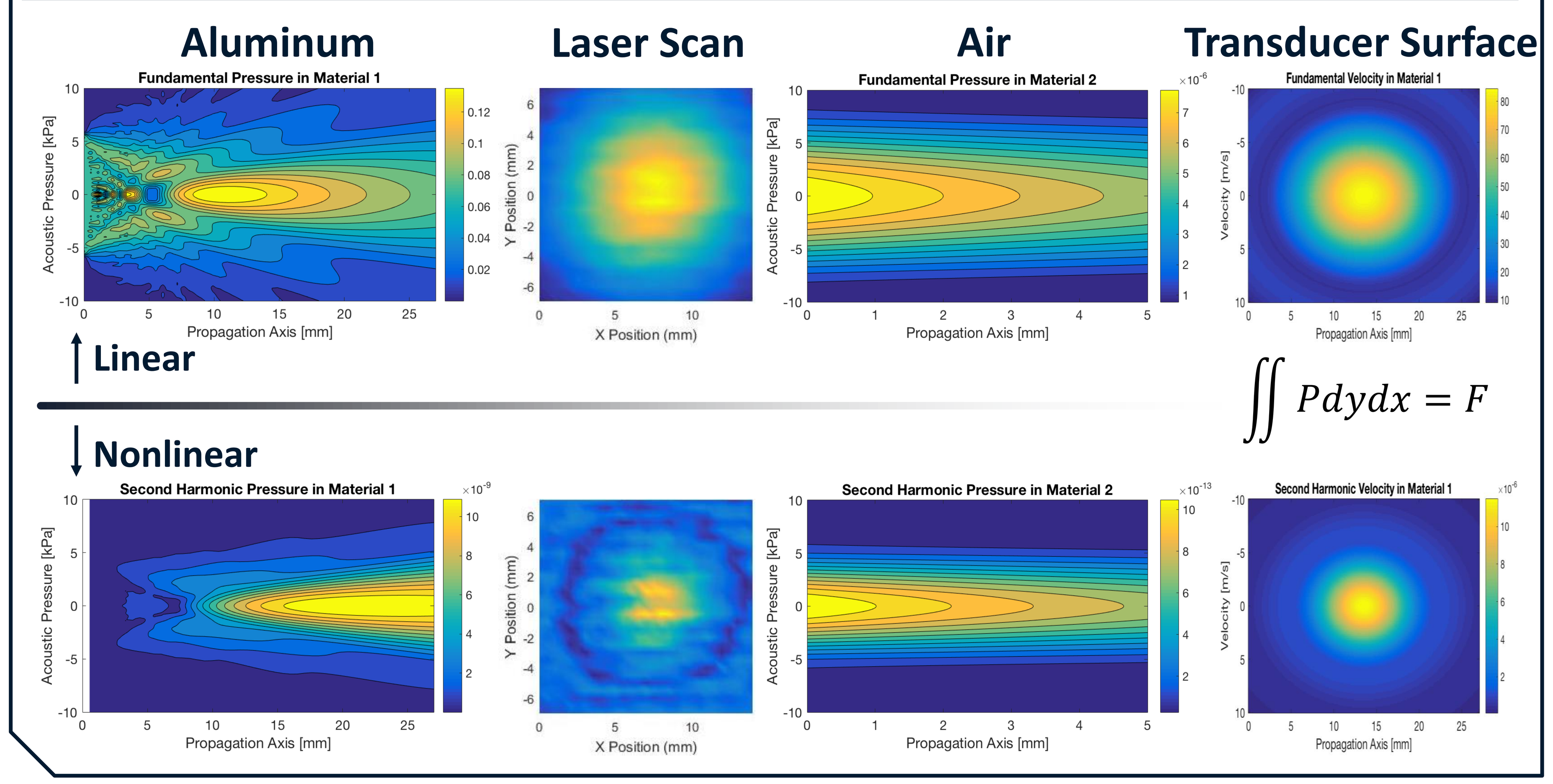




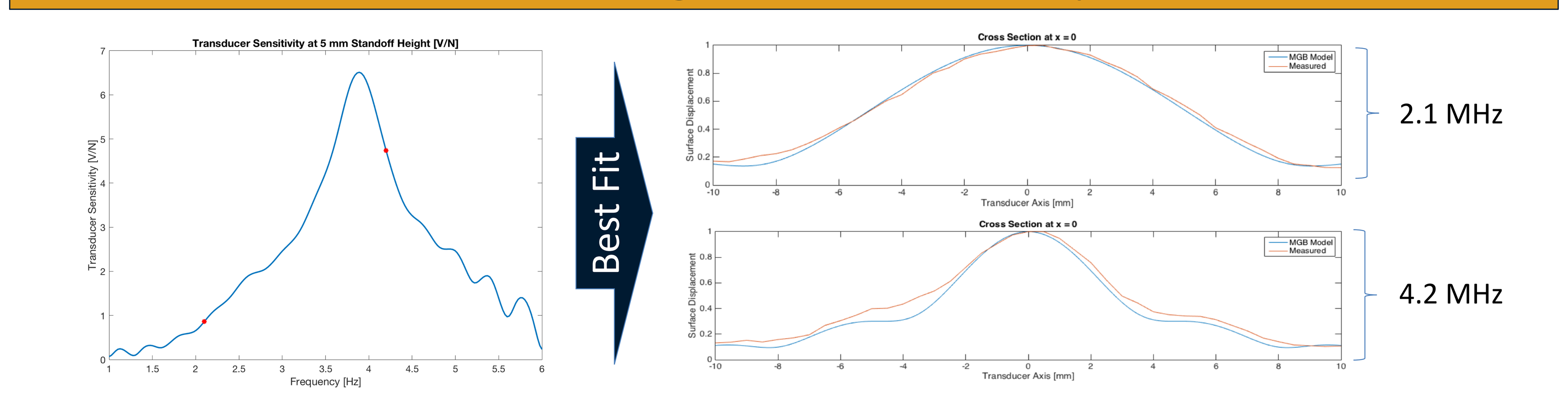
(1) RITEC 2500GA: Sinusoidal **signal generation** (1.8 MHz, 12 cycles)
(2) Lithium niobate **transducer**: Excitation of longitudinal wave in material, oil-coupled
(3) Material **Sample**: Aluminum 2024 or Fused Silica
(4) Ultran NCT4-D6 **air-coupled transducer**: Detection of plane wave
(5) Oscilloscope: Tektronix TDS5034B **Digital Oscilloscope**

Results and Discussion

Measurement Results



Data Fitting and Extraction of β



- Window time-domain waveform to **extract steady state signal**
- Waveform undergoes FFT to **extract amplitudes A_1 and A_2**, fundamental and first harmonic frequencies
- Plot transducer transfer function
- Employ best fit optimization to **calibrate transducer parameters**

$$\beta = 5.1$$

Values in literature range from 5 to 9.

Agrees with literature!

Conclusions

- Air-coupled transducers **can be calibrated inexpensively** using a contact transducer and a material with known nonlinear properties
- A **computational multiple Gaussian beam model** is provided and confirmed by laser interferometer results from material surface vibrations
- Measurement of **β matches expected value from literature**

References

[1] K. H. Matlack, J.-Y. Kim, J. Wall, J. Qu, and L. Jacobs. Proceedings of Meetings on Acoustics, 19, 045023, 2013.

[2] D. J. Shull, E. E. Kim, M. F. Hamilton, and E. A. Zabolotskaya. JASA, 97(4):2126–2137, 1995.

[3] J. Wen , M. Breazeale. JASA, 83(5):1752–1756, 1988.