Active Damping of Ultrasonic Receiving Sensors Through Engineered Pressure Waves

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1 Introduction

Narrowband ultrasonic transducers typically exhibit ringing in their temporal response to an excitation. When driven by a short burst signal, the ringing dominates the overall vibration response.

The pressure wave causes significant ringing if the receiver is also narrowband. The large time-duration can severely limit the time-resolution[1], making it difficult to separate signals with close arrival times.

Current measurement techniques focus mostly on damping the transmitted pressure wave only[2-5], which can still lead to significant receiver ringing.

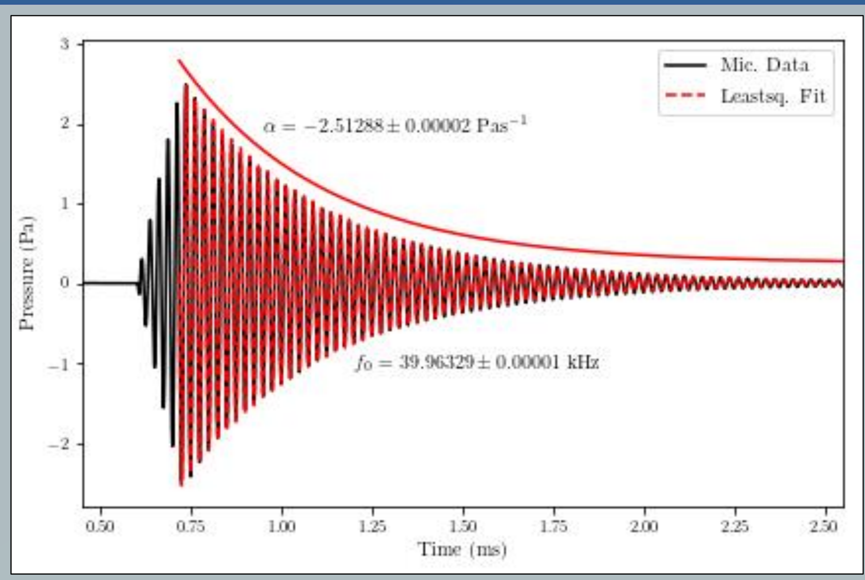
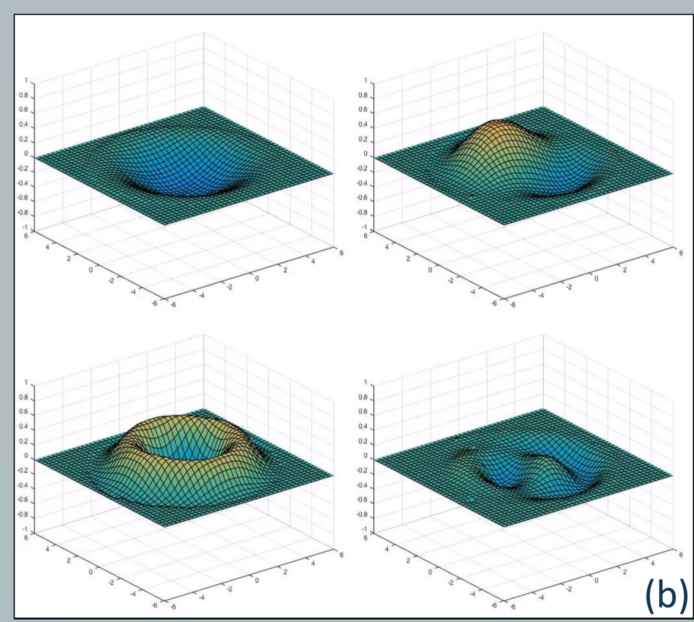


FIG 1. The extended ringing (highlighted red) of a narrowband FUT, driven with a 6 cycle 40 kHz sinusoidal input.

2 The Flexural Ultrasonic Transducer

Active damping in reception is demonstrated using the FUT, a narrowband transducer comprising a piezoelectric ceramic bonded to a metallic plate, often titanium or aluminium. The piezo-plate system is electro-mechanically coupled, with its vibration behaviour dominated by the properties of the plate, considered as edge-clamped[1,6].



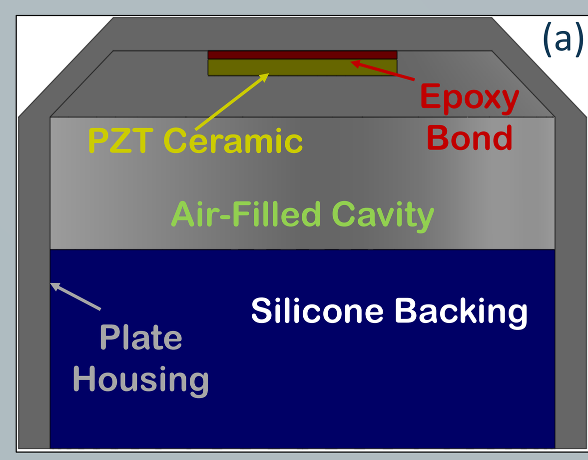


FIG 2. A schematic diagram of the FUT (a), and the first four bending modes of its metallic plate (b)[6].

3 Analogue Model Description

- Time dependent displacement of the FUT's plate is approximated by a mass-spring-damper system[1].
- Assigns electrical and mechanical properties of entire system to single M, C, and K constants.

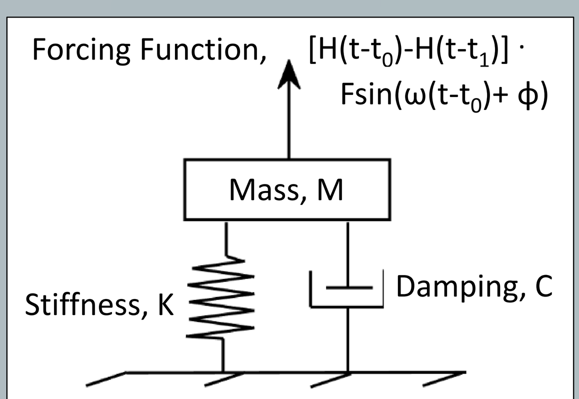


FIG 3. Analogue model schematic.

- Solution contains three distinct regions of vibration.
- Fit ring-down section to find M,C, and K for an individual transducer and use to predict its response to sequences of gated sinusoids[7].

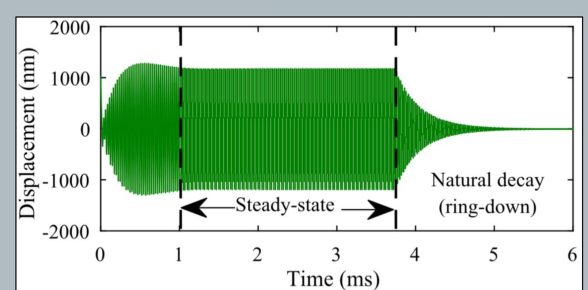


FIG 4. Response of a typical 40 kHz FUT driven at resonance with an 150 cycle input. Shows build-up, steady-state, and ring-down stages.

4 Characterising the FUT

FUTs are sensitive to changes in their boundary conditions[8], so characterisation must be performed 'in-situ'. It is often impractical to do this using a microphone, instead we exploit the FUT's electro-mechanical coupling to characterise the far-field pressure it produces.

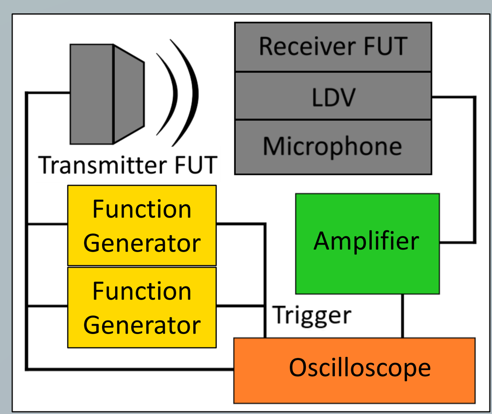


FIG 5. Set-up for active damping and characterisation measurements.

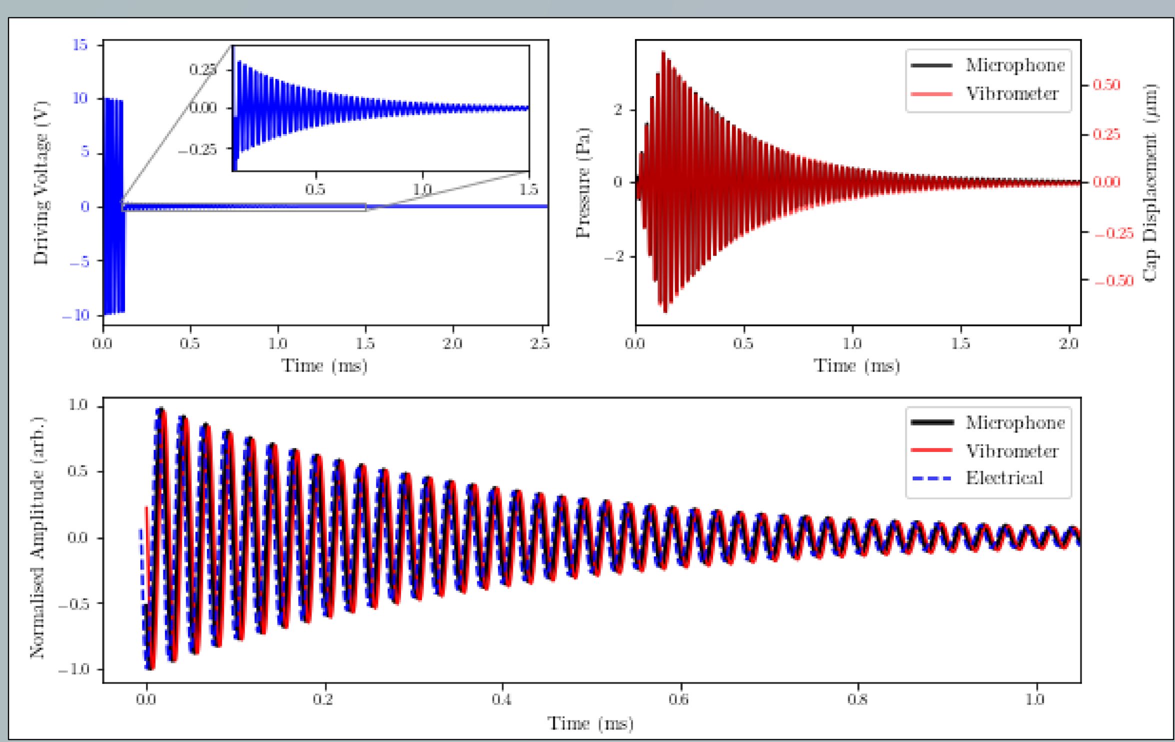


FIG 6. Correlation in the ring-down response of a transmitting FUT when measured using, laser Doppler vibrometry (black). An acoustic microphone (red), and through the electro-mechanical coupling effect (blue).

5 Active Damping

After extraction of MCK parameter groups for a transmitting FUT (T_X) and a receiving FUT (R_X), numerical modelling is used to simulate the response of the transmit-receive system to various inputs comprising gated sinusoids[7]. A pulse sequence is designed in the numerical system that minimises the duration of R_X's response.

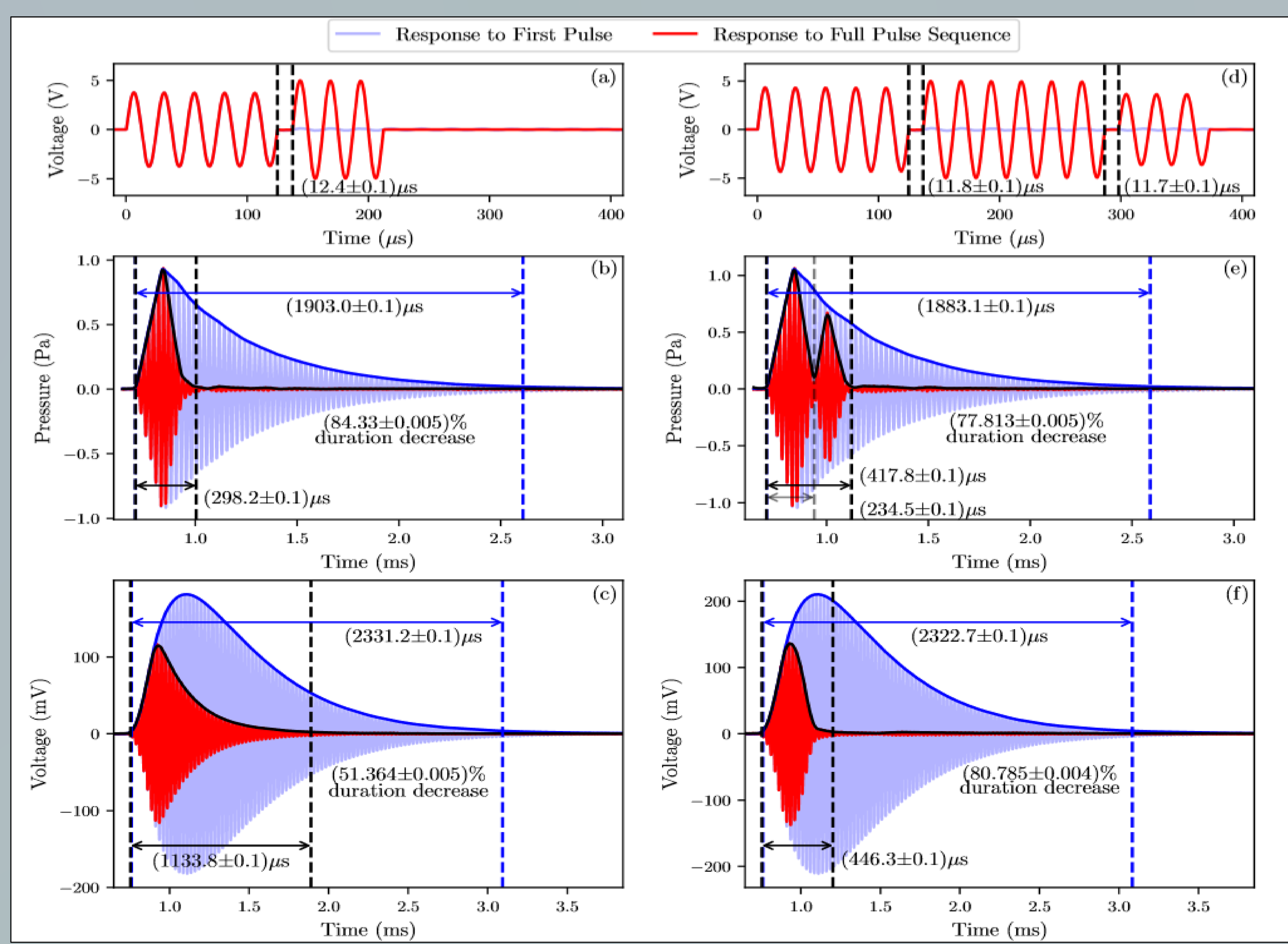


FIG 7. Comparison between active damping methods to reduce the response duration of (a)-(c) T_X, and (d)-(f) R_X, showing (a),(d) the electrical pulse sequence used to drive T_X; (b),(e) the far-field ultrasonic pressure produced by T_X; (c),(f) the voltage output of R_X.

FIG 7. shows this approach applied to a pair of commercially available 40 kHz FUTs, with a comparison to active damping methods[2,3,7] designed to minimise the duration of T_X's response. In both cases, the unwanted ringing is damped through the application of a driving force in anti-phase with the ringing response. To minimise the duration of R_X, a secondary pulse of ultrasonic air pressure is created timed to be in anti-phase with the R_X response.

6 Creating the Damping Pressure Wave

An electrical pulse sequence of three gated sinusoids is used to drive T_X to create a pressure wave that excites, and subsequently damps R_X. Other sequences could be envisioned[7].

An initial pulse is used to excite T_X and R_X.

A second pulse drives in anti-phase with R_X, designed to reduce the vibration of R_X to zero in the shortest possible time.

The ringing of T_X in response to the second pulse 'over-drives' R_X, so a third pulse is used to damp T_X's ringing.

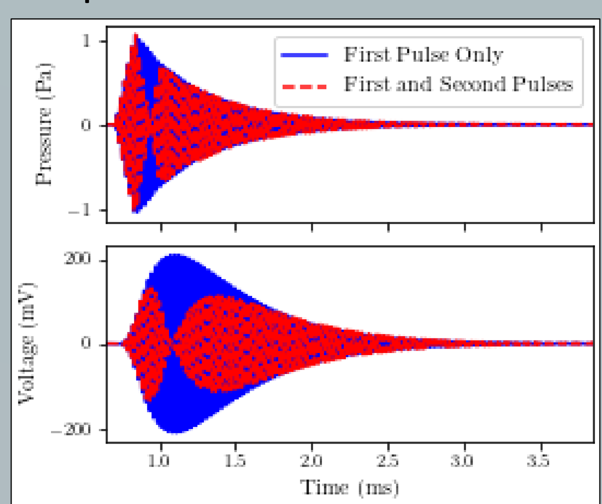


FIG 8. Far field pressure response of T_X (top) and voltage output of R_X (bottom) to the first (blue) and first and second pulses (red).

7 Conclusion

A pressure wave can be created that minimises the ringing of a narrowband receiving transducer, producing an 80% decrease in duration when compared to the free system with no damping methods applied. This method is can be used even in situations where the properties of the transmitter and receiver are unmatched (different MCK parameter groups), as is the case in most industrial settings.

8 Ongoing Research

- MCK parameter groups are found for transducers in this experiment using their transmission characteristics. Since FUTs are only weakly non-linear, this is a good first approximation; however, characterisation of the receiver using a wideband acoustic source (such as a WEMDAT) may achieve more accurate results.
- The sensitivity of the FUTs to their clamping (boundary) conditions may be somewhat alleviated by considering the system as a vibrating plate with elastic edge supports. This may loosen the requirement that the transducers must be characterised 'in-situ'.
- A full mathematical model to describe the transmitter-receiver system is being produced, which would alleviate the need for numerical modelling.
- Considering the electrical properties of the FUT would assist in impedance matching between TX, RX, and the electrical equipment.

References

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