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euspen's Special Interest Conference in
Micro/Nano Manufacturing & 6th AET
Symposium on ACSM and Digital Manufacturing

Simulation-Driven Design of Ultrasonic Horns for Precision Micro-Grinding Applications

Presented by

Dr. Rajeshkumar Madarkar & Prof. Sabuj Mallik

**School of Engineering and the Built Environment
Buckinghamshire New University**





Outline

- ❑ Introduction to Ultrasonic Horns
- ❑ Working Principle and Design Considerations
- ❑ Proposed Methodology for Horn Development
- ❑ Materials Used for Horn Manufacturing
- ❑ Finite Element Analysis and Simulation Results
- ❑ Applications: UVAG and UMQL
- ❑ Summary and Future Outlook



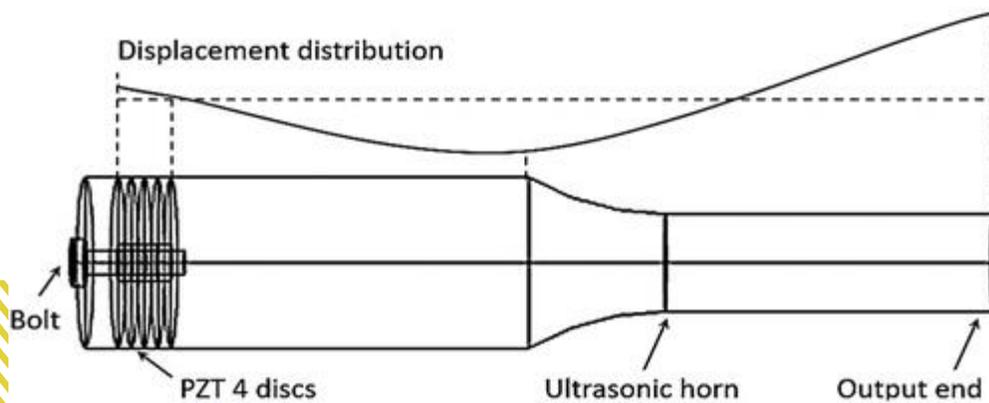
What Are Ultrasonic Horns?



- Ultrasonic horns are **specially designed tools** that vibrate at ultrasonic frequencies (e.g., 20 kHz) in a longitudinal mode.
- They are mainly used in thermoplastic welding, machining and other precision applications.
- Performance depends on two key factors:
 - ❑ Uniform vibration amplitude at the horn's working tip
 - ❑ Low internal stress under operational loads (to prevent failure)
- Horns must be precisely tuned to their operating frequency for optimal efficiency and safety.
- The part where it sees light in the modern-day science is in the various applications related to usage of ultrasound.



Different types of ultrasonic welding horns for varied industrial applications.



Schematic of an ultrasonic transducer-horn assembly showing displacement distribution



Ultrasonic horn with transducer assembly



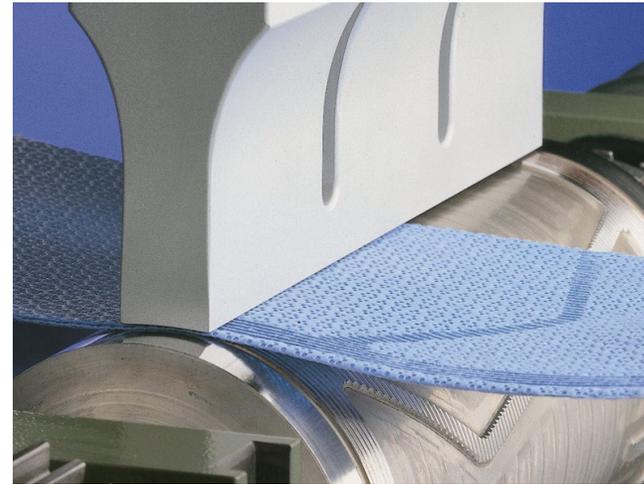
What Are Ultrasonic Horns?



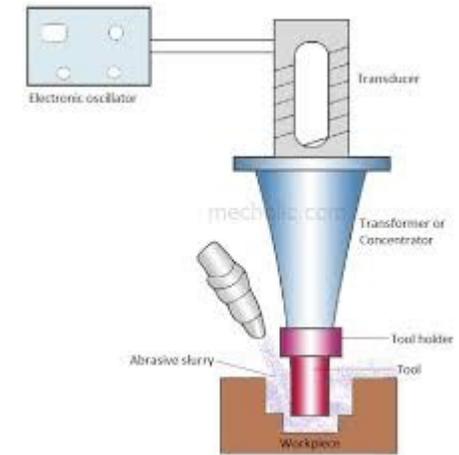
*Ultrasonic Processor
(Sonicator)*



*Ultrasonic Cutter with Titanium
Blade Horn Best Price for
Industrial Applications*



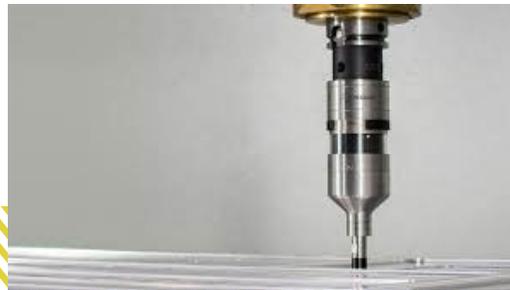
Ultrasonic Welding



*Ultrasonic
Machining*



*Ultrasonic Welding of Face Mask Strap
Using Ultrasonic Horn*



*Ultrasonic Assisted Machining Setup
for Precision Material Removal*



*Ultrasonic Surgical
System*



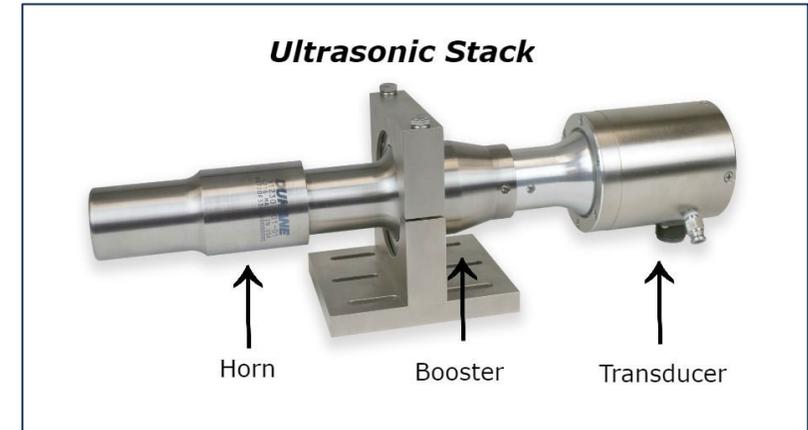
*Bench-Top Ultrasonic Cleaning Unit
with Built-in Transducers for
Precision Cleaning Applications*



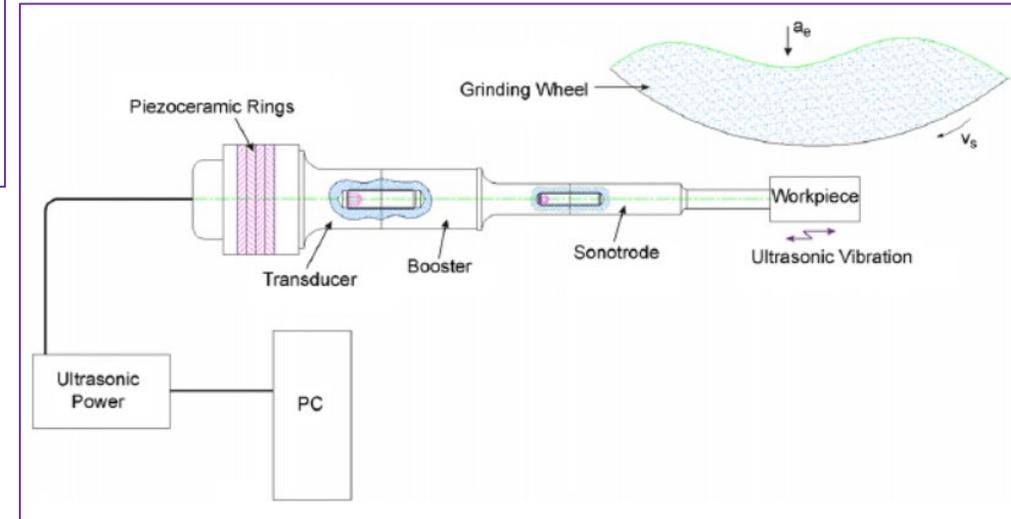
Important elements of ultrasonic vibration system

- Ultrasonic generator
- Piezoelectric transducer
- Booster
- Horn*

**Special attention is needed for designing and manufacturing of the horn correctly which may otherwise hamper the performance and cause significant damage to the ultrasonic unit*



Ultrasonic Stack with Transducer, Booster, and Horn

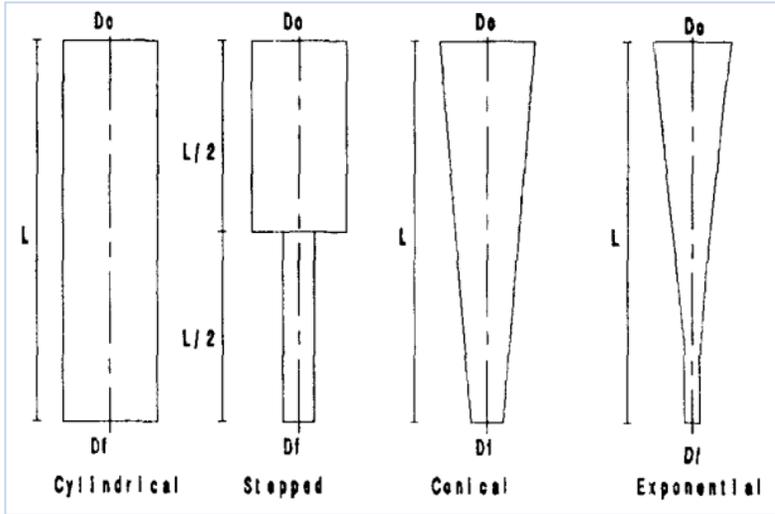


Scheme of the UVAG experimental setup

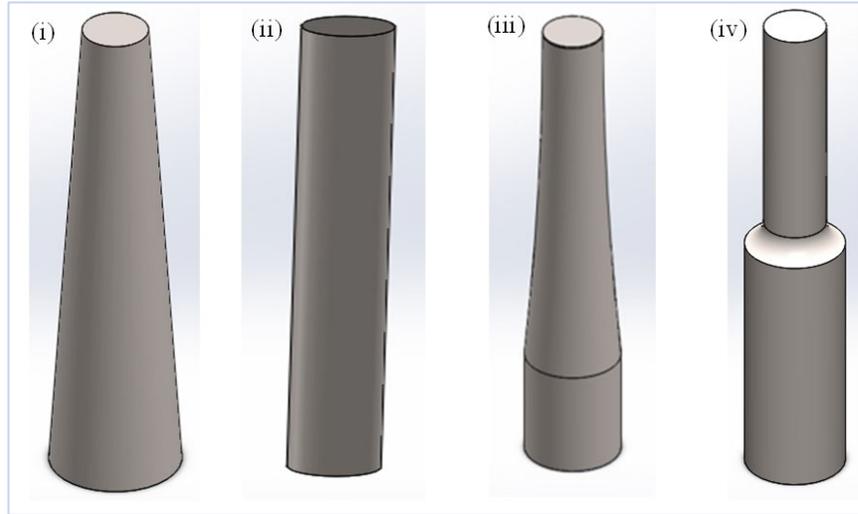




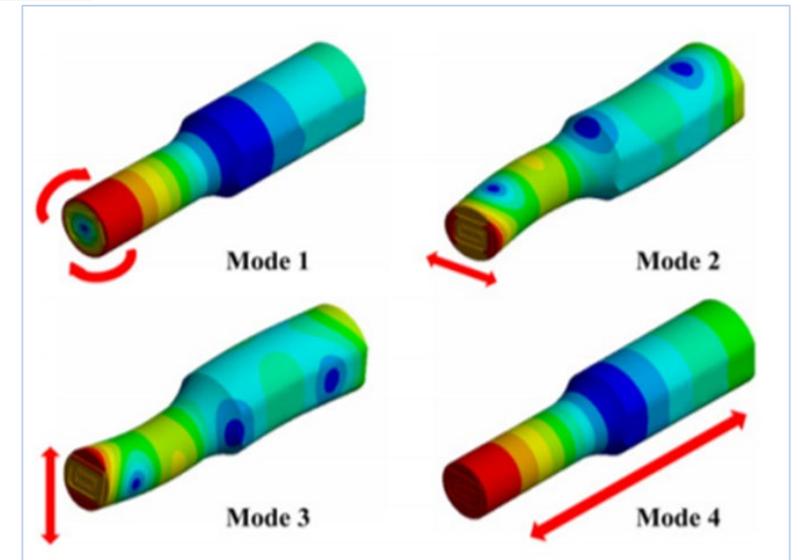
Types of horn



Traditional horn contours



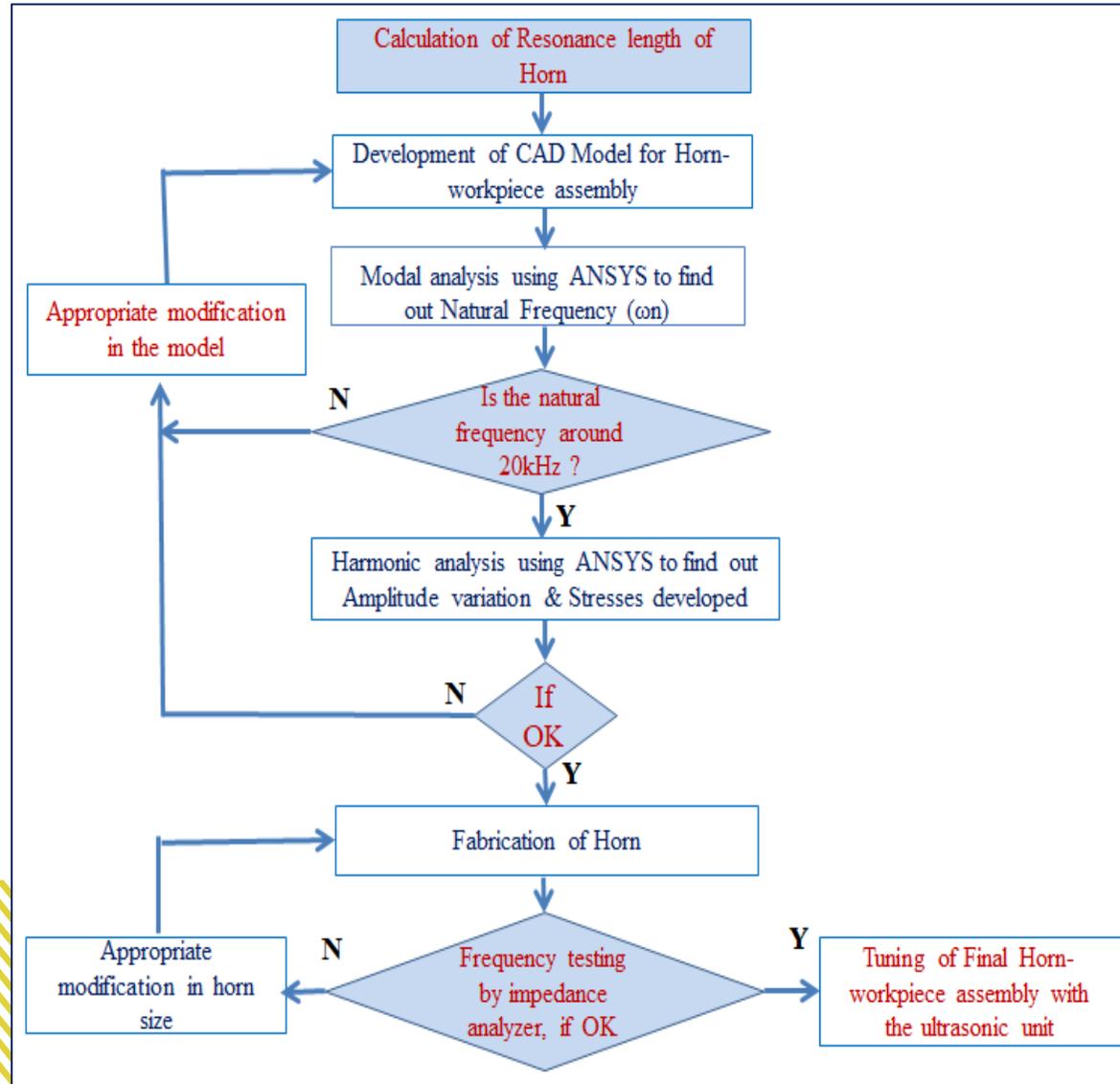
Common types of horn shapes: (i) conical, (ii) cylindrical, (iii) exponential, and (iv) stepped.



Different mode shape results: (Mode 1) twisting, (Mode 2) transverse (horizontal), (Mode 3) transverse (vertical), and (Mode 4) longitudinal

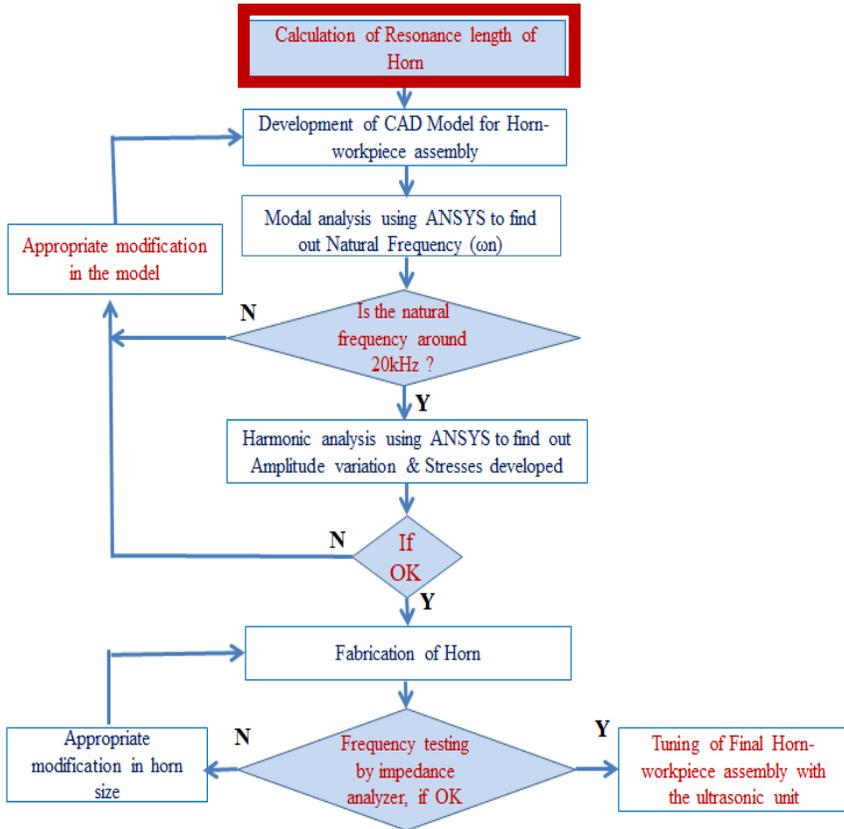


Proposed methodology for the development of Horn: Simulation-Driven Design of Ultrasonic Horns





Proposed methodology for the development of Horn: Simulation-Driven Design of Ultrasonic Horns



- The resonant length (L) can be calculated from the following equation:

$$L = \frac{c}{2f} \quad \text{-----(i)}$$

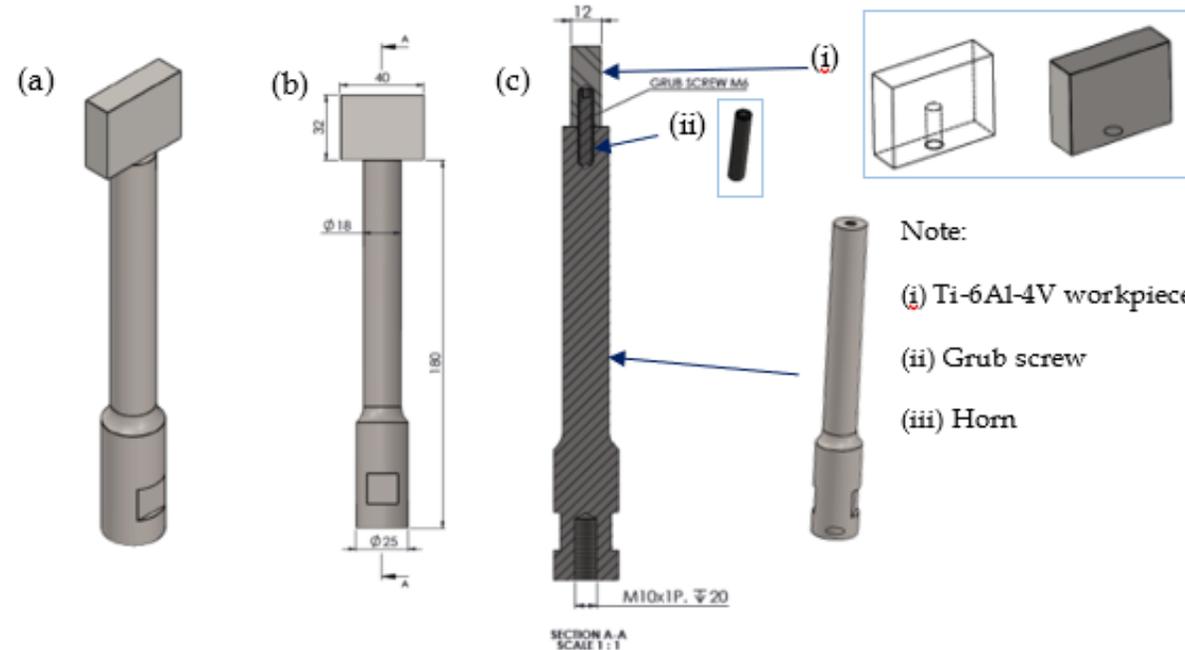
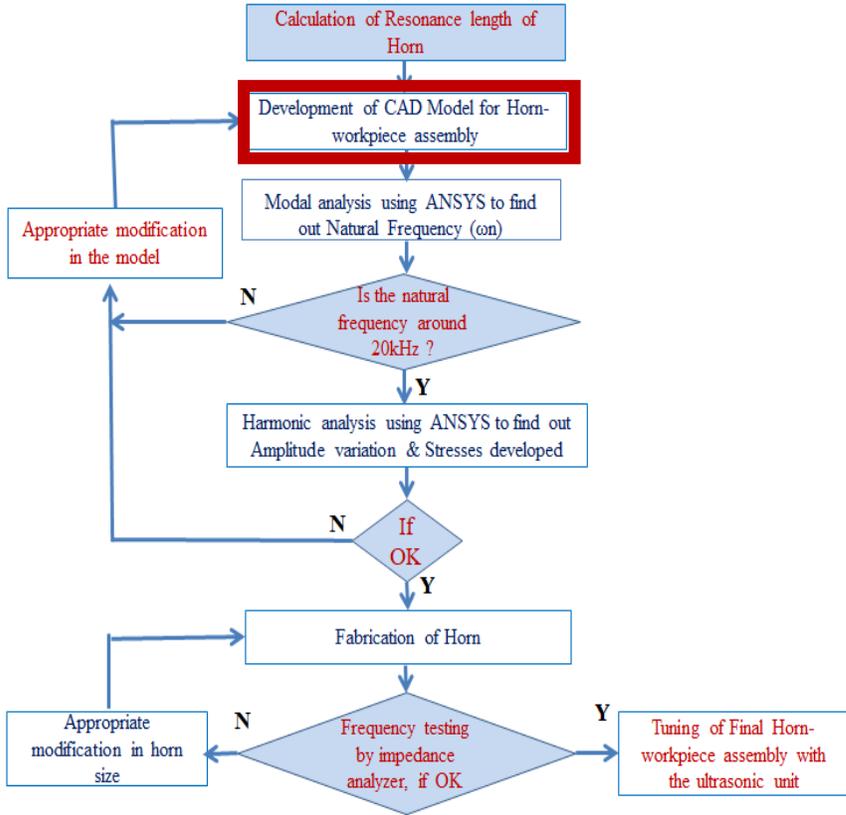
where, c is the wave propagation velocity which is defined as:

$$C = \sqrt{\frac{E}{\rho}} \quad \text{-----(ii)}$$

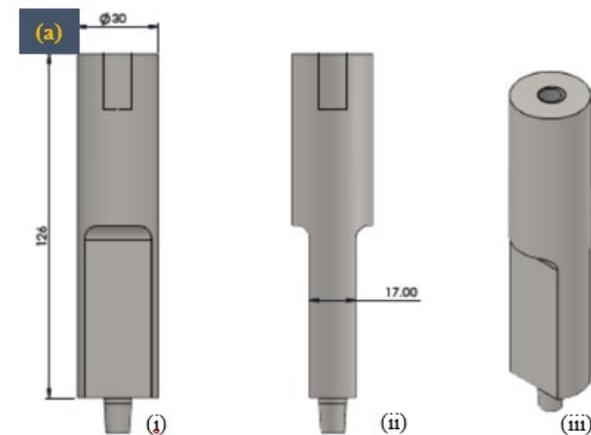
- Eq. (1) is used to calculate an approximate length of the stepped horn and provides the **initial geometrical dimension for FEM simulation.**



Proposed methodology for the development of Horn: Simulation-Driven Design of Ultrasonic Horns



(A) The CAD model of horn-workpiece assembly (a) Isometric view, (b) side view, (c) section view

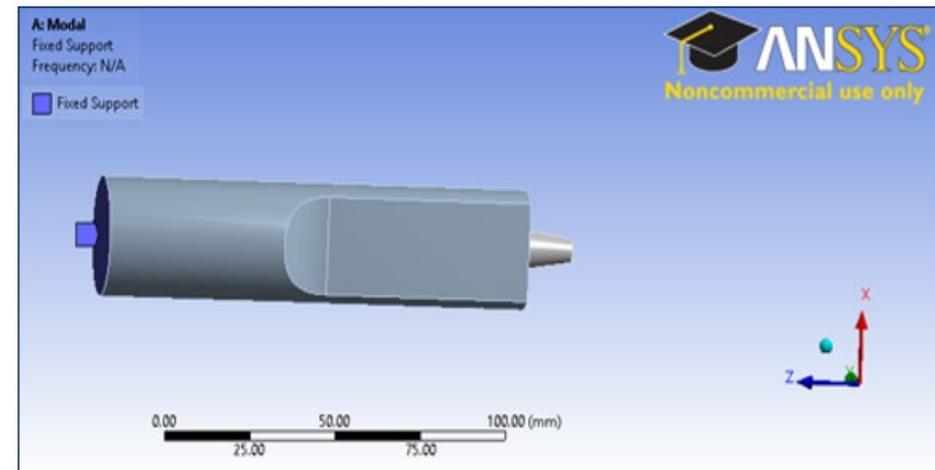
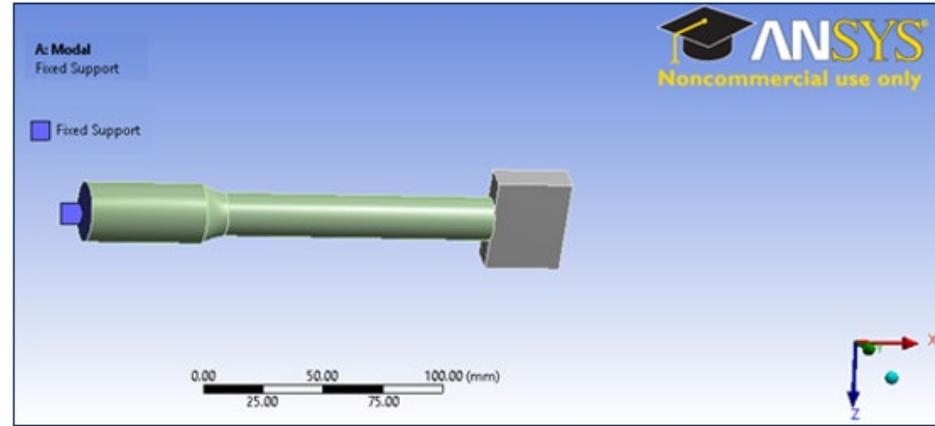
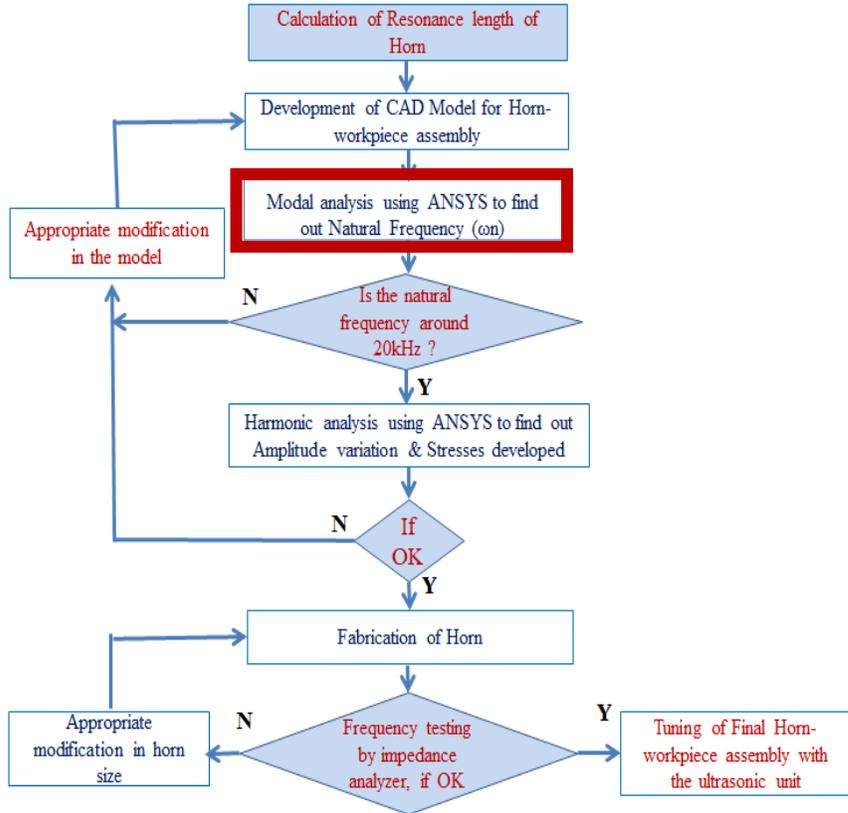


CAD model of the horn (i) isometric view, (ii) front view, (iii) side view,





Proposed methodology for the development of Horn: Simulation-Driven Design of Ultrasonic Horns

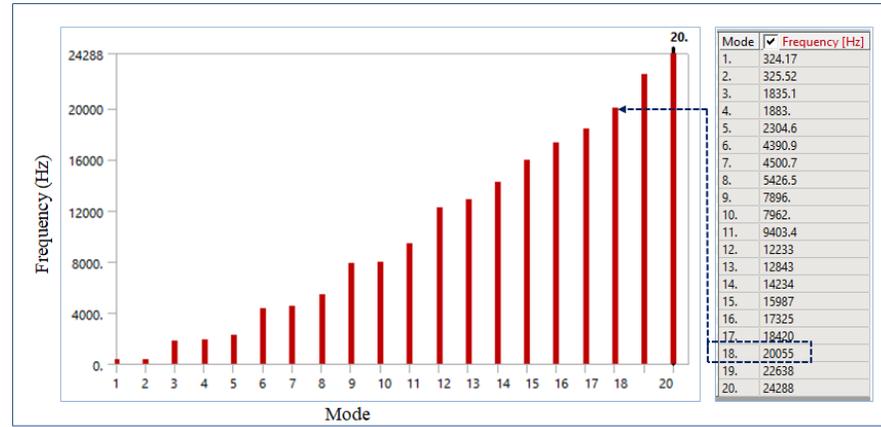
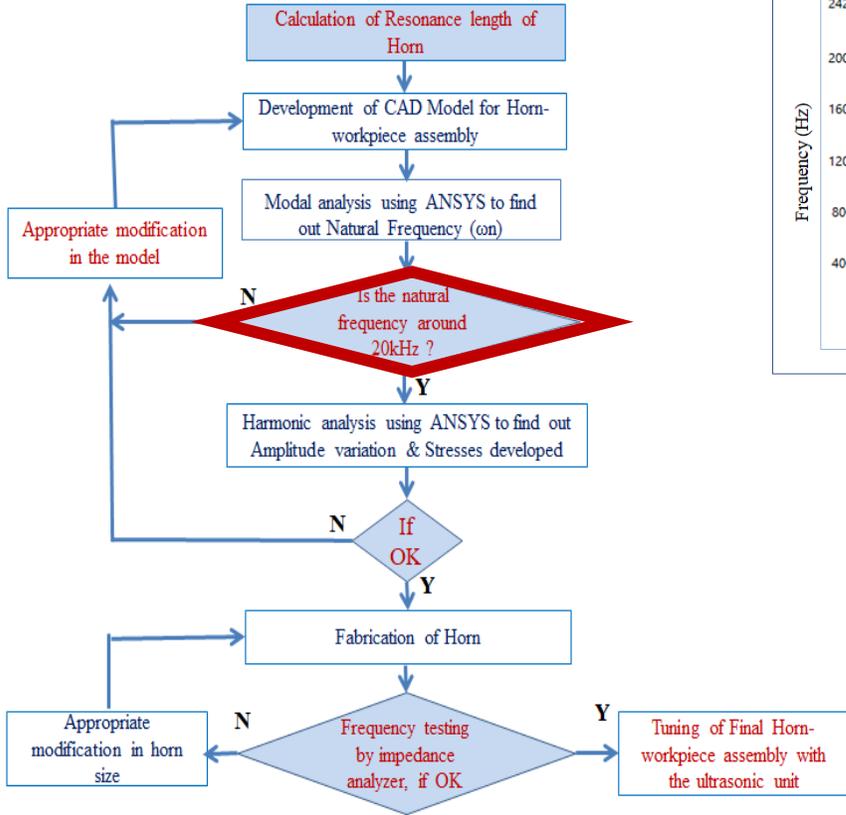


Modal analysis using ANSYS workbench

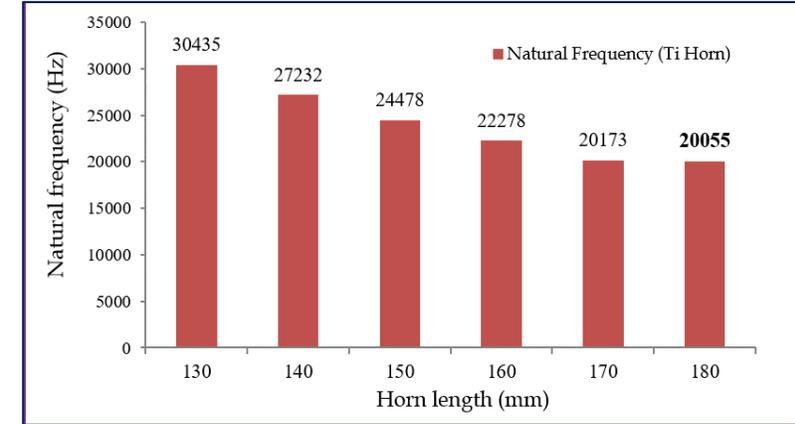




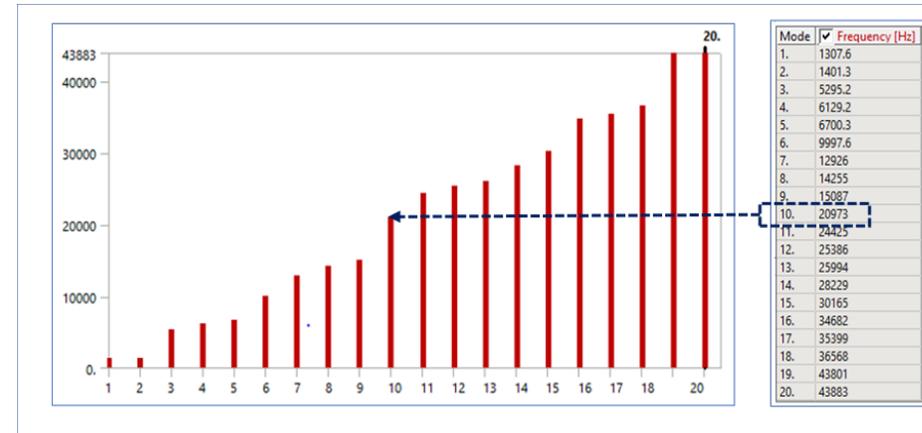
Proposed methodology for the development of Horn: Simulation-Driven Design of Ultrasonic Horns



The modal solutions of the acoustic horn.



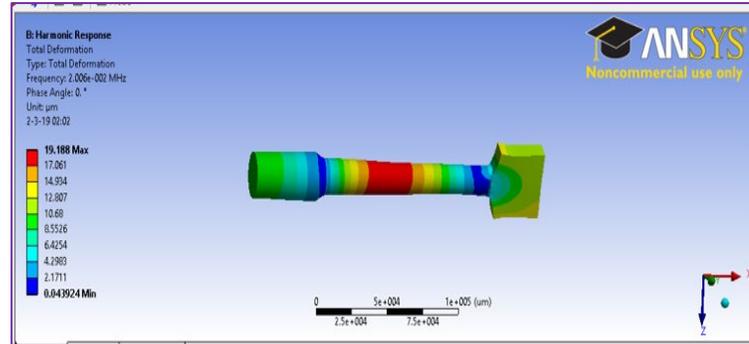
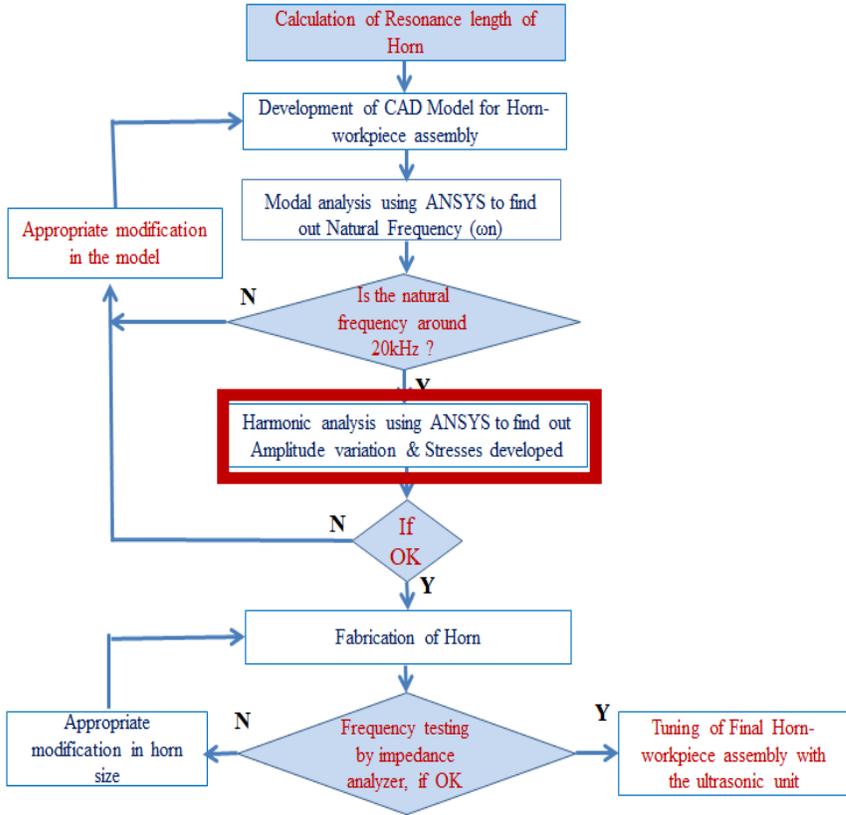
Natural frequency of the Horn at different horn length.



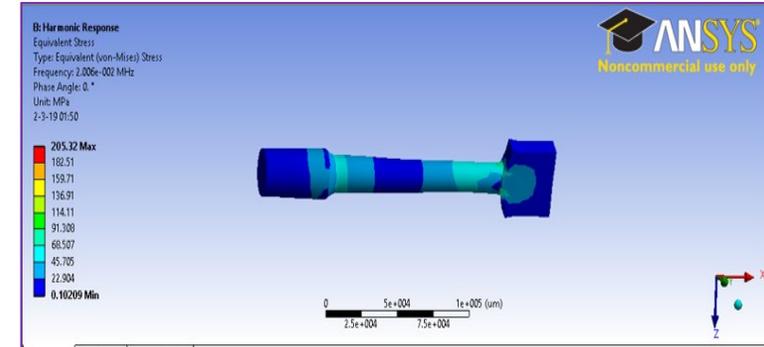
The modal solutions of the acoustic horn.



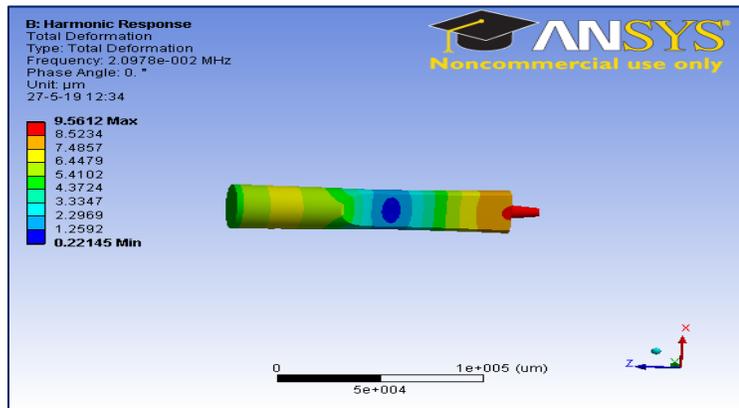
Proposed methodology for the development of Horn: Simulation-Driven Design of Ultrasonic Horns



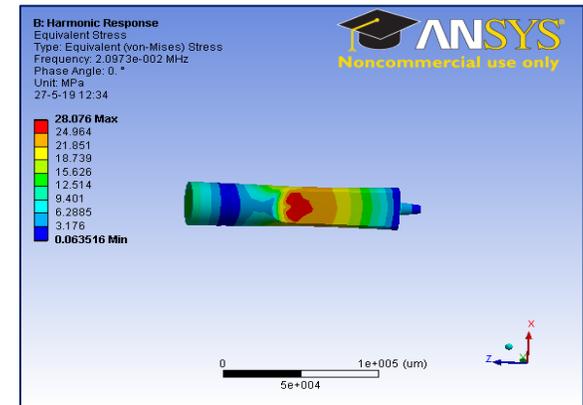
Harmonic response: Total Deformation.



Harmonic response: Equivalent Stress.



Harmonic response: Total Deformation.

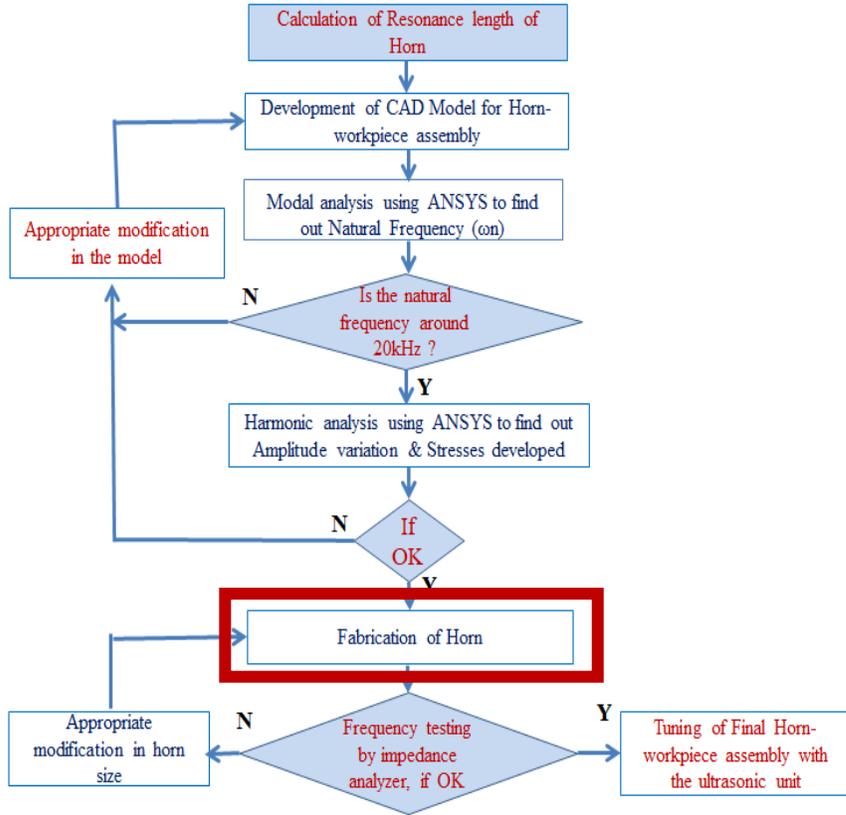


Harmonic response: Equivalent Stress.





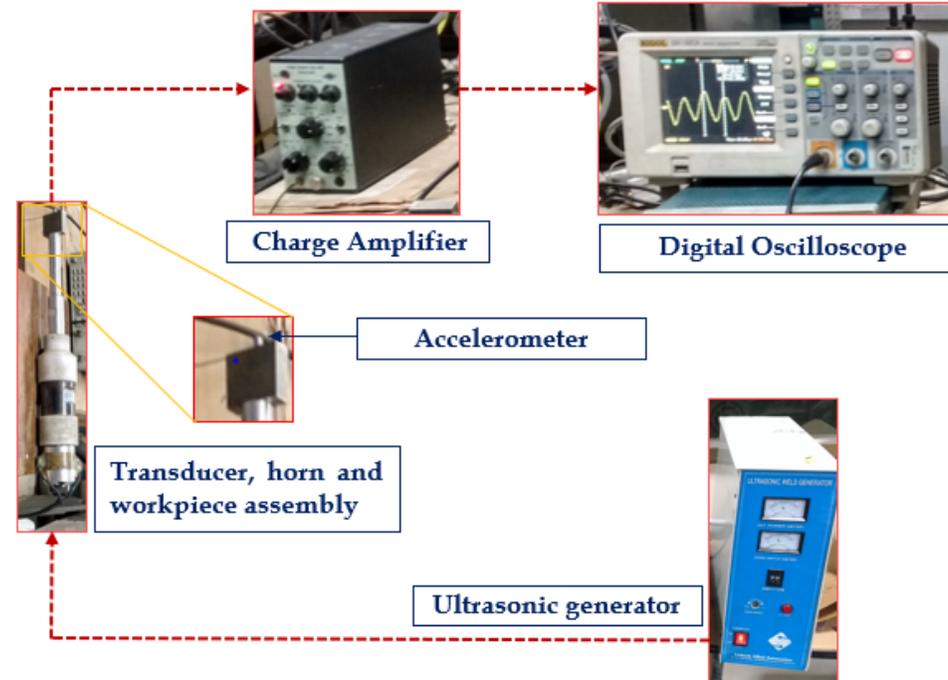
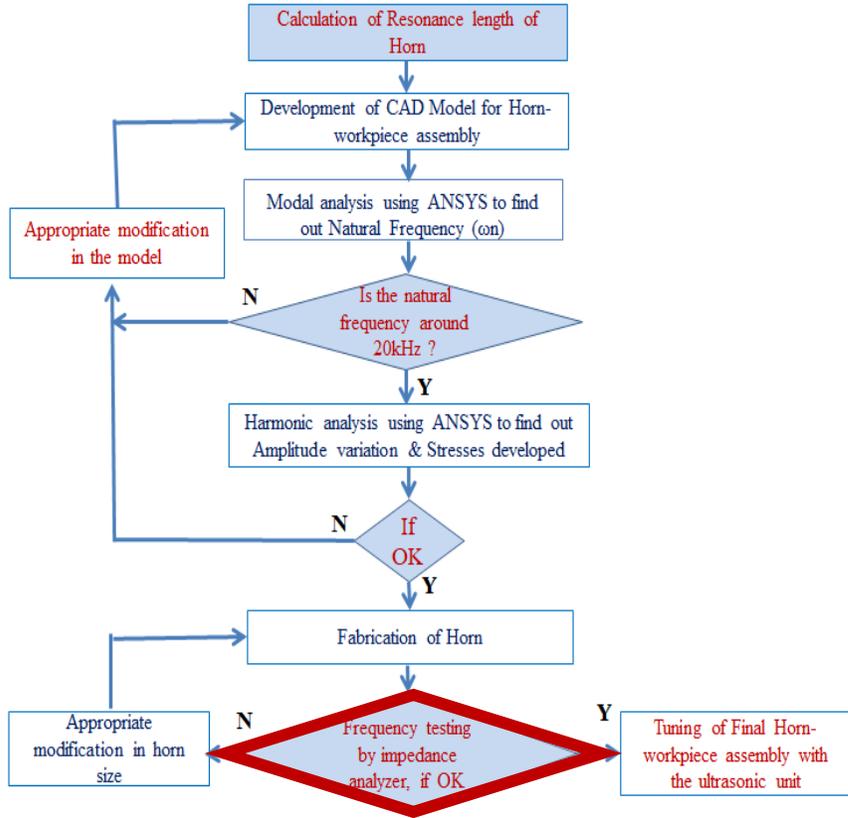
Proposed methodology for the development of Horn: Simulation-Driven Design of Ultrasonic Horns



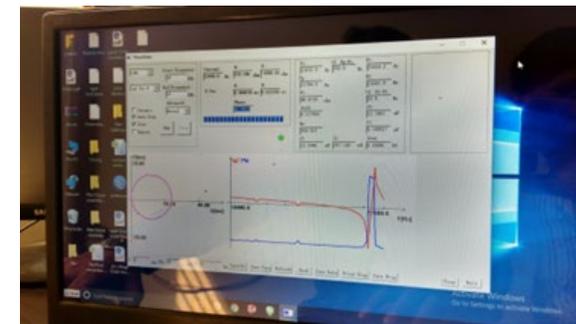
Photographs of the developed horns



Proposed methodology for the development of Horn: Simulation-Driven Design of Ultrasonic Horns



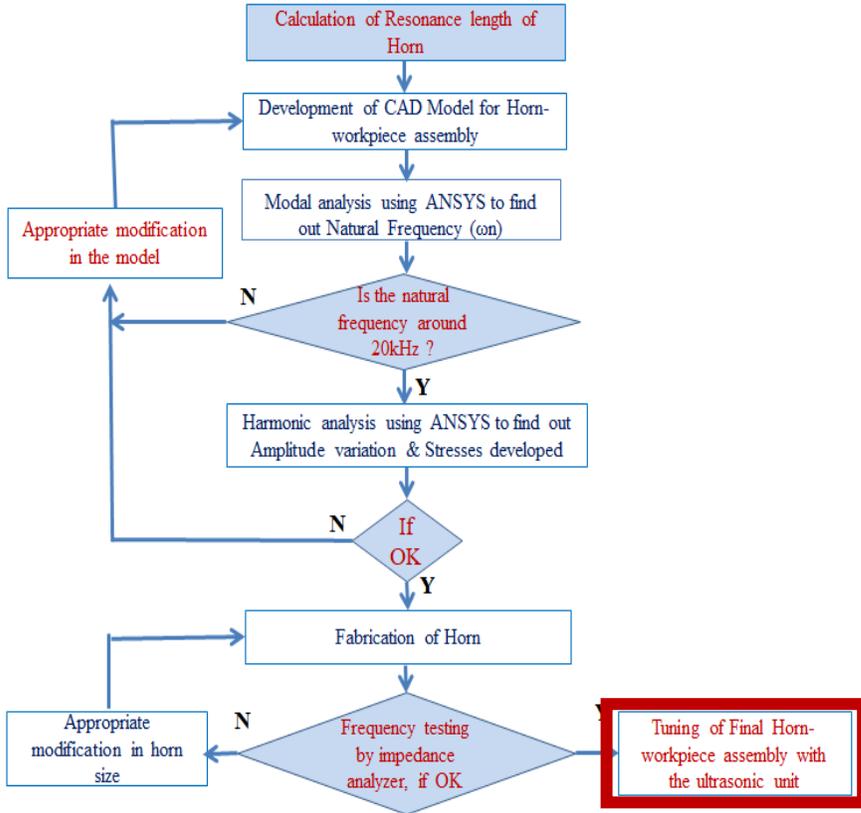
Experimental Setup for Ultrasonic Vibration Monitoring Using Accelerometer and Oscilloscope



Impedance-frequency response of the horn assembly at ~20 kHz resonance



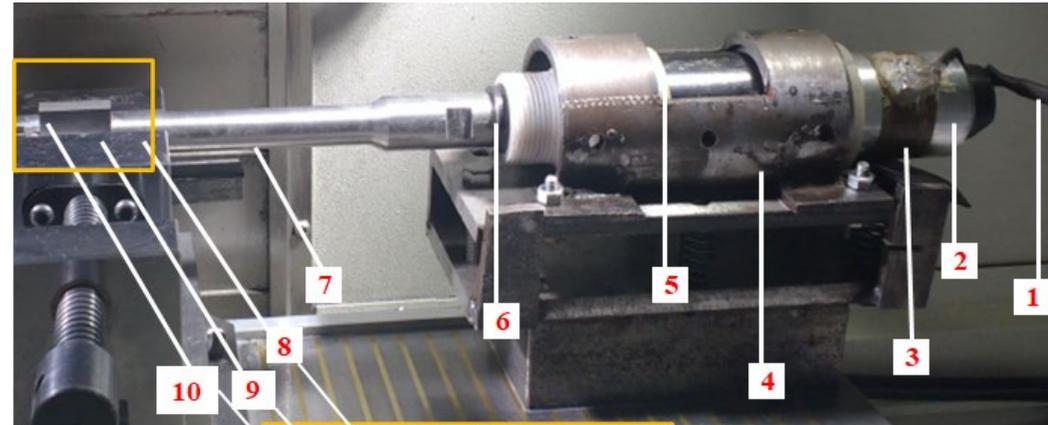
Proposed methodology for the development of Horn: Simulation-Driven Design of Ultrasonic Horns



Photograph of cutting fluid droplet being atomized into fine droplets due to the ultrasonic vibration of the horn



Photograph of the developed UMQL setup on the grinding machine



Photograph of UVAG setup:
 1. ultrasonic power supply cable,
 2. transducer, 3. piezoelectric rings,
 4. transducer fixture, 5. vibration isolation,
 6. booster, 7. horn,
 8. workpiece fixture,
 9. vibration isolator,
 10. Ti-6Al-4V workpiece,

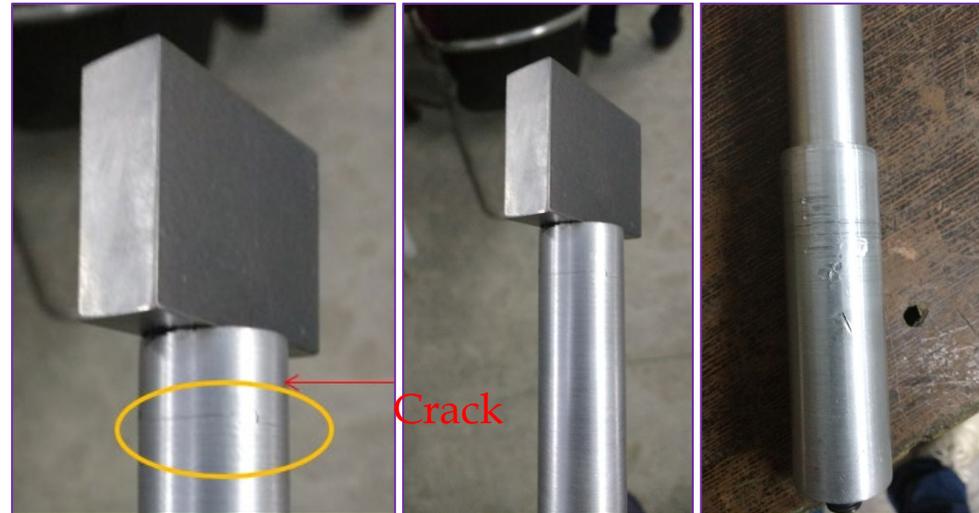


Right Material for making Horns?

- ❑ Vibrates **like a spring**, stretching and shrinking at **20,000 cycles/sec (20 kHz)**
- ❑ Acts as a **half-wavelength resonant bar** during operation
- ❑ Continuously under **tension and compression** forces
- ❑ Requires materials with **high fatigue strength** and **acoustic efficiency**
- ❑ Common horn materials: **Titanium, Aluminum, Steel**

Aluminum Horn

- Low strength
- Crack
- Thread damage after some cycle of vibration
- Difficulty in achieving tight assembly of horn and workpiece as workpiece get loosened after some cycle of vibration



Titanium is preferred as it has high tensile strength, high toughness even at extreme temperatures, light weight and good acoustic properties

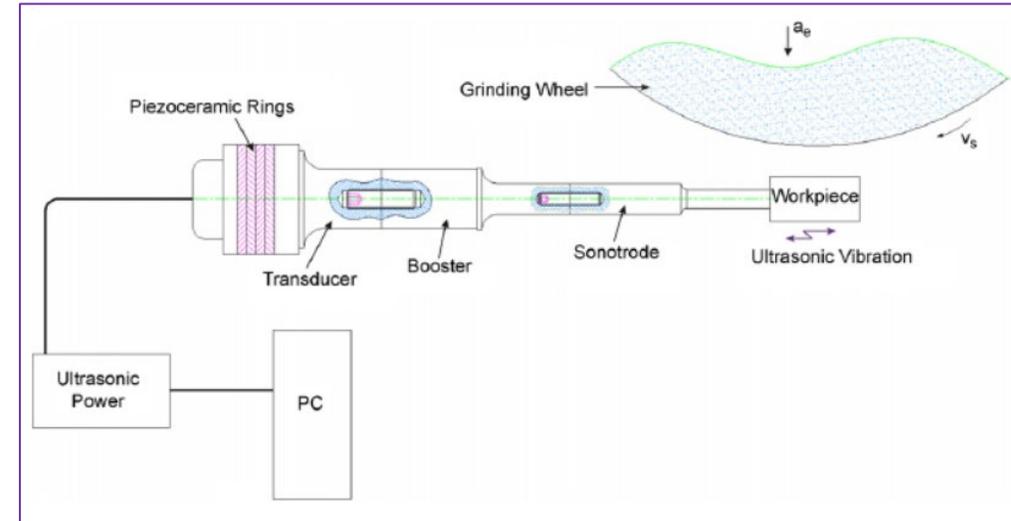
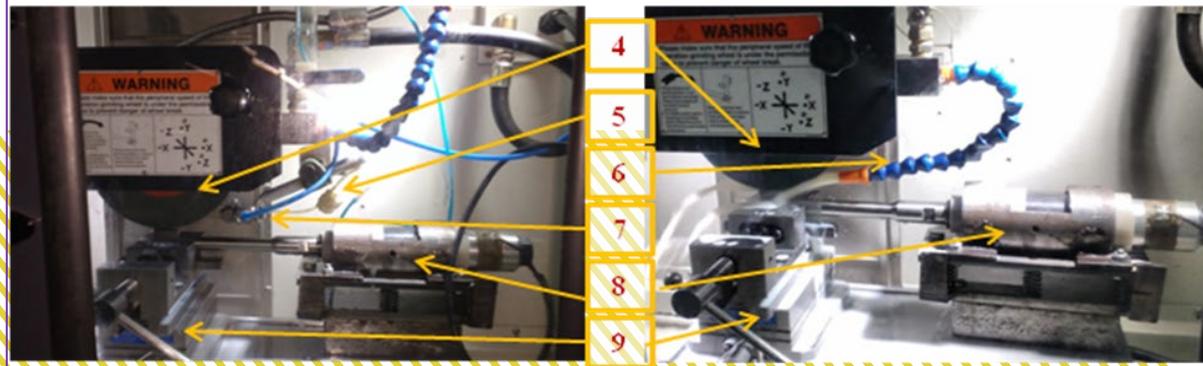
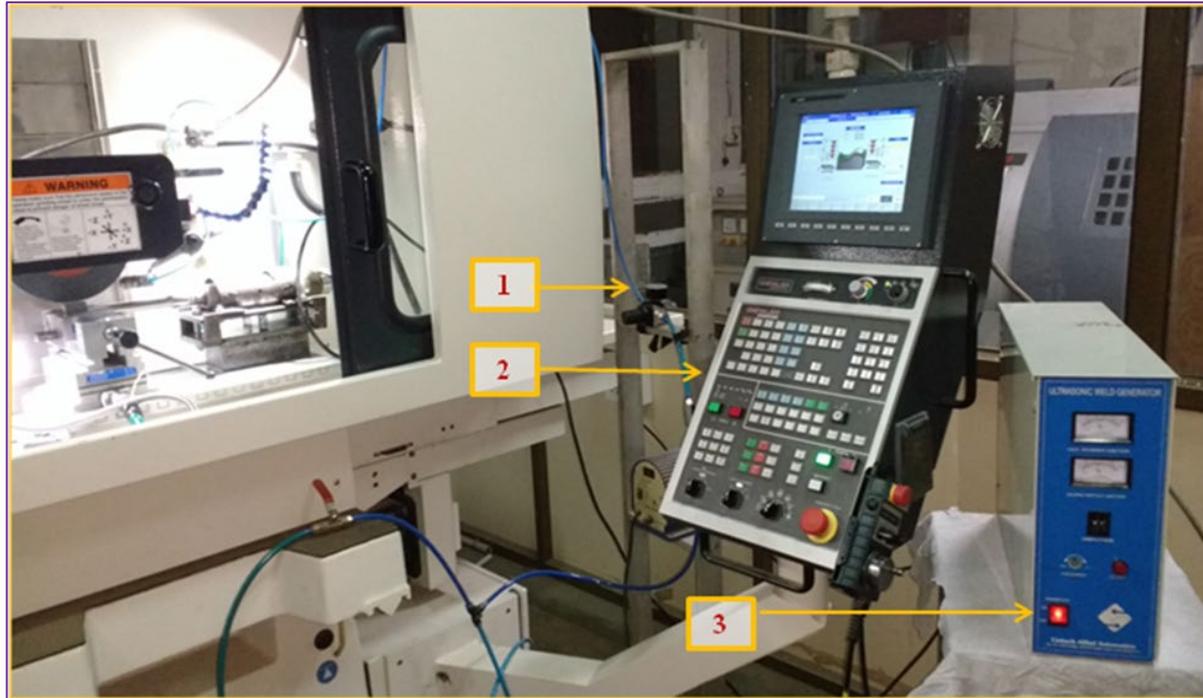


Aluminum horn showing cracks after vibration cycles compared with durable titanium horn.



Precision Micro-Grinding Applications: UVAG

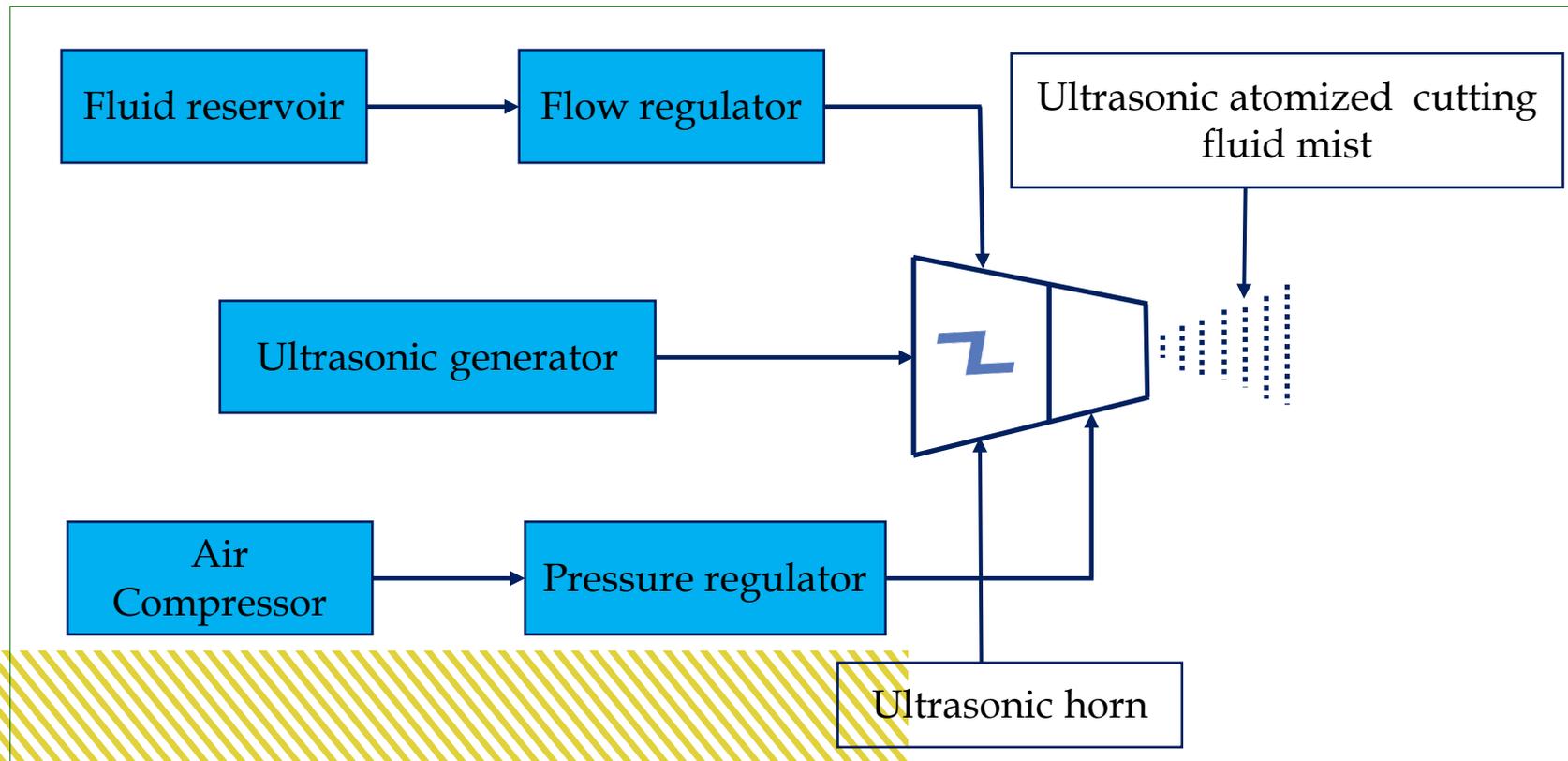
Developed UVAG setup on the grinding machine



Scheme of the UVAG experimental setup



Ultrasonic vibration assisted minimum quantity lubrication (UMQL) system

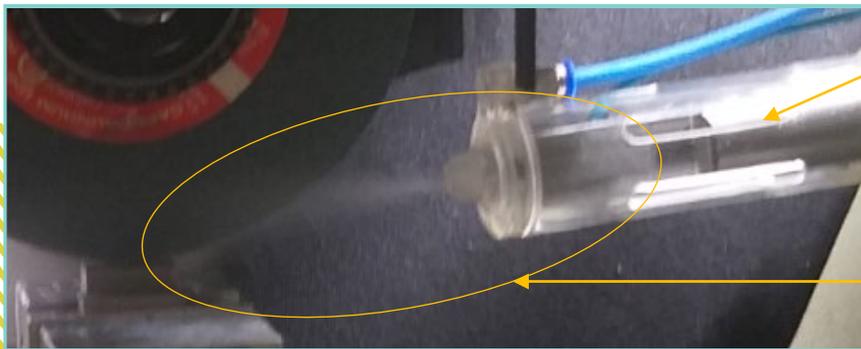


Schematic diagram of Ultrasonic vibration assisted minimum quantity lubrication (UMQL) system

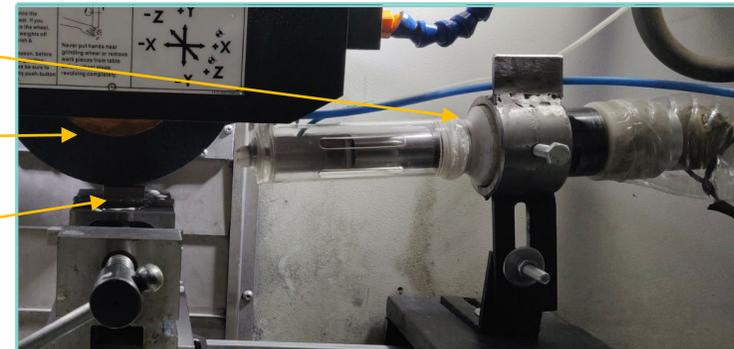


Application: UMQL

Developed UMQL setup on the grinding machine



- UMQL setup
- SiC Wheel
- Ti-6Al-4V workpiece
- Mist





Summary & Outlook

Summary

- ❑ Finite Element Method (FEM) enables precise tuning and structural optimization of ultrasonic horns.
- ❑ FEA-guided horn design ensures frequency matching and prevents fatigue or resonance failure.
- ❑ Optimized designs enhance performance in UVAG and UMQL applications.

Outlook

- ❑ AI-driven horn shape optimization using genetic algorithms or neural networks
- ❑ Integration of multi-physics simulation (piezoelectric-thermal-fluid) for advanced accuracy
- ❑ Smart ultrasonic systems with real-time frequency tuning and health monitoring





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Thank you! Questions?

Dr. Rajeshkumar Madarkar

(Lecturer in Engineering)

Buckinghamshire New University

Email ID: rajesh.madarkar@bucks.ac.uk