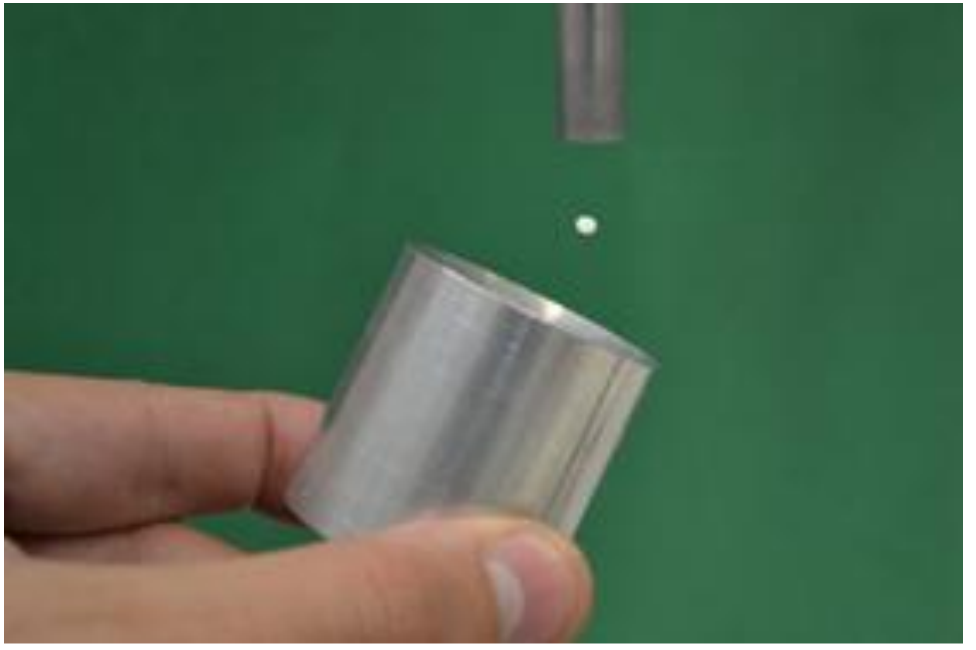

Particle manipulation by a non-resonant acoustic levitator

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Acoustic levitation

Let's first watch a video …

Contents

- What is acoustic levitation?
- Brief historical background
- Current applications
- Particle manipulation by a non-resonant acoustic levitator
  - Concept
  - Hardware & Construction
  - Mathematical Model
  - Simulation
  - Conclusion

What is acoustic levitation?

- Acoustic levitation *(also: Acoustophoresis)* is a method for suspending matter in a medium by using acoustic radiation pressure from intense sound waves in the medium.

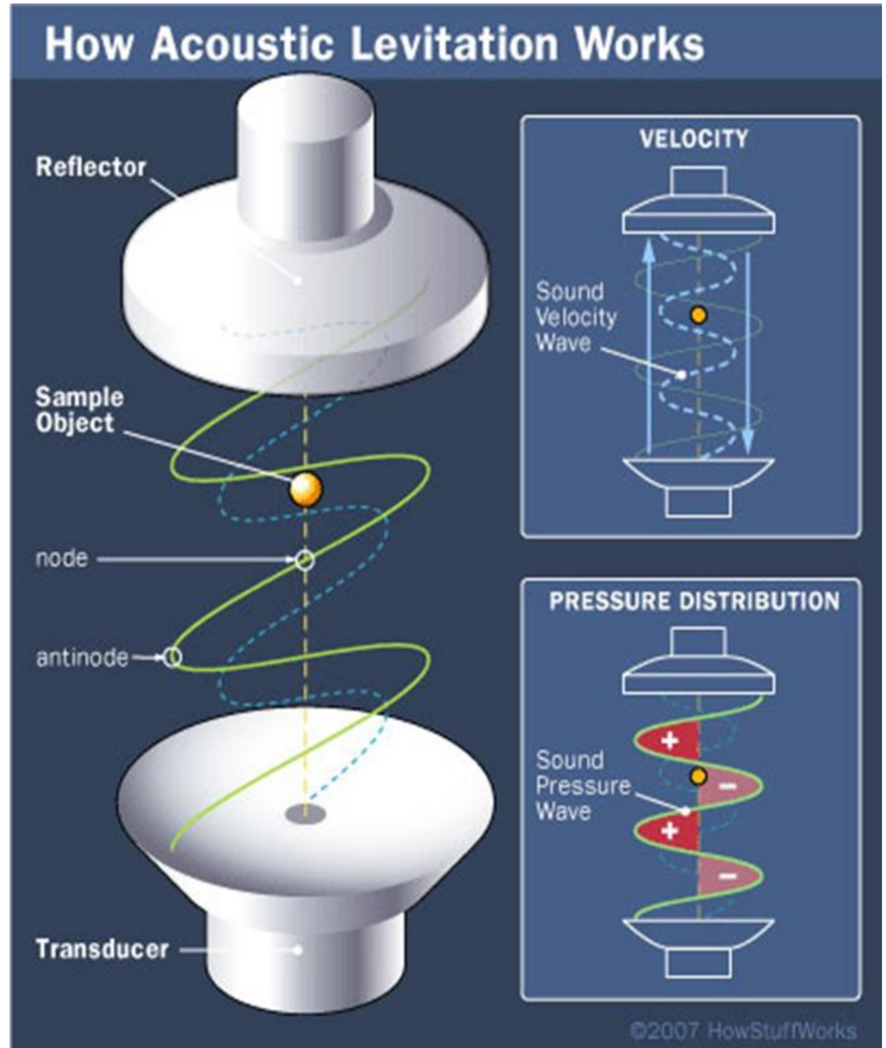
- "**Acoustophoresis**" means migration with sound, i.e., "phoresis" – migration and "acousto" – sound waves are the executors of the movement.

What is acoustic levitation?

- To understand how acoustic levitation works:
  - First know that **gravity is a force** that causes objects to be pulled towards the earth.
  - Second, **air is a fluid** and like liquids, air is made of microscopic particles that move in relation to one another.
  - Third, **sound is a vibration** from a sound's source and as it moves or changes shape very rapidly it creates oscillations creating sound. A series of **compressions** and **rarefactions**. Each repetition is one **wavelength** of the sound wave.
- Acoustic levitation uses sound traveling through a fluid (air) to balance the force of gravity.

Physics of Sound Levitation

- A basic acoustic levitator has two main parts –
  - a transducer, which is a vibrating surface that makes sound,
  - and a reflector.
- A sound wave travels away from the transducer and bounces off the reflector.

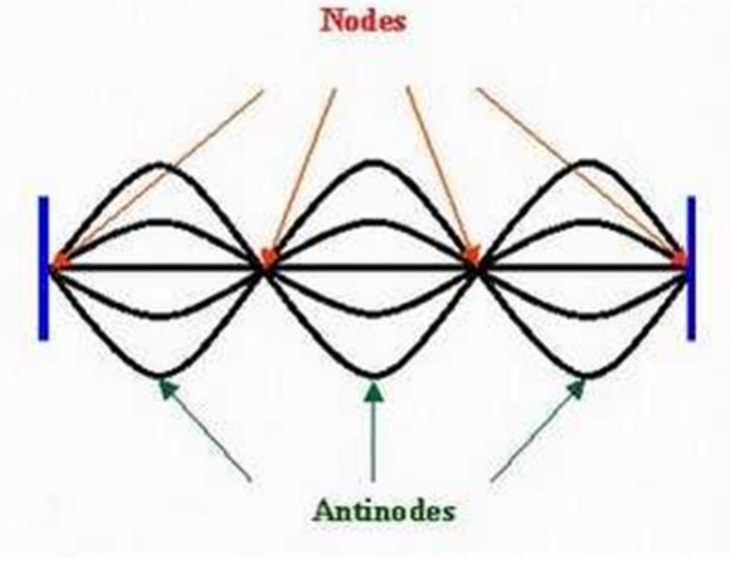


Physics of Sound Levitation

- The interaction between compressions and rarefactions causes interference.
- Compressions that meet other compressions amplify one another, and compressions that meet rarefactions balance one another out.
- The reflection and interference can combine to create a standing wave.
- Standing waves appear to shift back and forth or vibrate in segments rather than travel from place to place.
  - *This illusion of stillness is what gives standing waves their name.*
- *Standing sound waves have defined nodes, or areas of minimum pressure, and antinodes, or areas of maximum pressure.*

Physics of Sound Levitation

- A standing wave's nodes are at the heart of acoustic levitation.
- Imagine a river with rocks and rapids. The water is calm in some parts of the river, and it is turbulent in others. Floating debris and foam collect in calm portions of the river.
- In order for a floating object to stay still in a fast-moving part of the river, it would need to be anchored or propelled against the flow of the water.
- This is essentially what an acoustic levitator does, using sound moving through a gas in place of water.

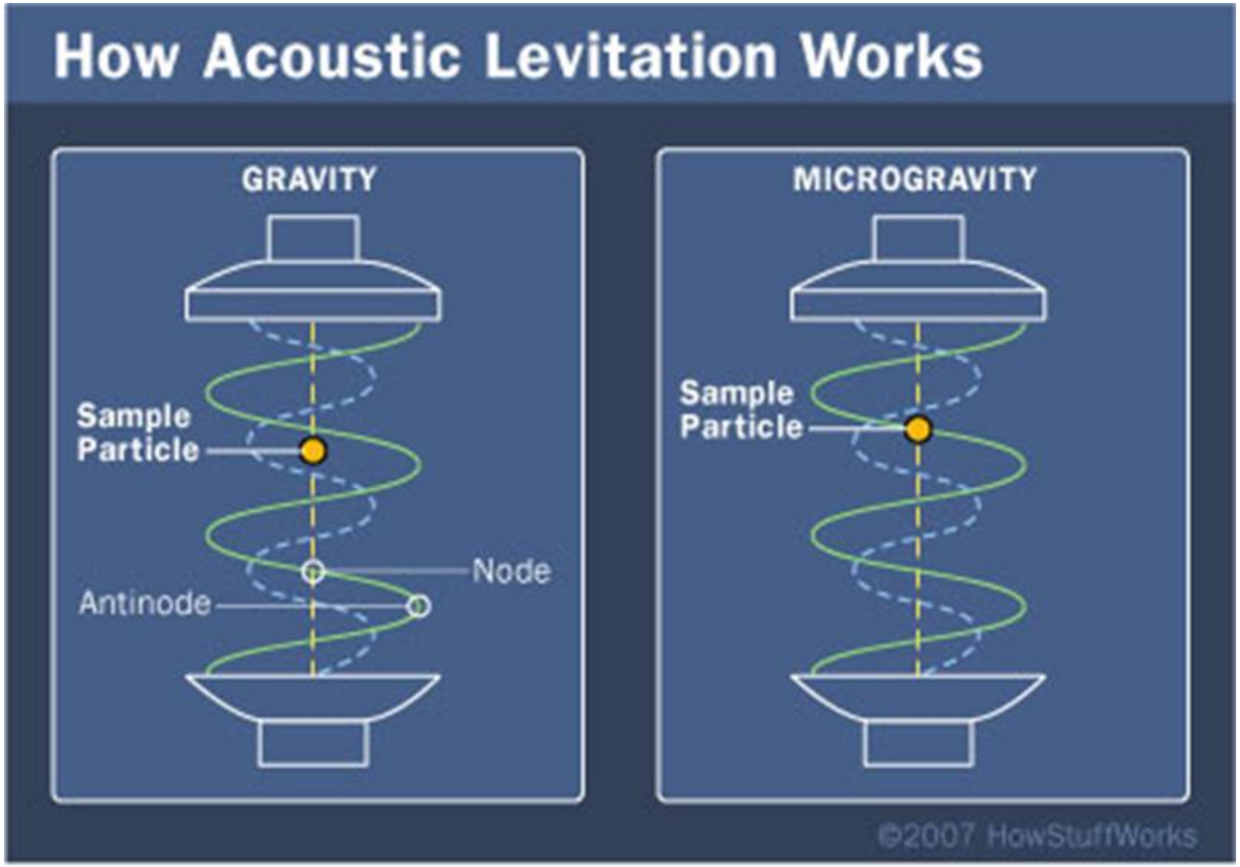


Physics of Sound Levitation

- By placing a reflector the right distance away from a transducer, the acoustic levitator creates a standing wave.
- When the orientation of the wave is parallel to the pull of gravity, portions of the standing wave have a constant downward pressure and others have a constant upward pressure. The nodes have very little pressure.

Physics of Sound Levitation

- In space, where there is little gravity, floating particles collect in the standing wave's nodes, which are calm and still.
- On Earth, objects collect just below the nodes, where the acoustic radiation pressure, or the amount of pressure that a sound wave can exert on a surface, balances the pull of gravity.



On earth In space

Historical Background

Historical Background

Piezoelectric Basins for Acoustic Levitation
Identified at Megalithic Sites

Historical Background

Applications

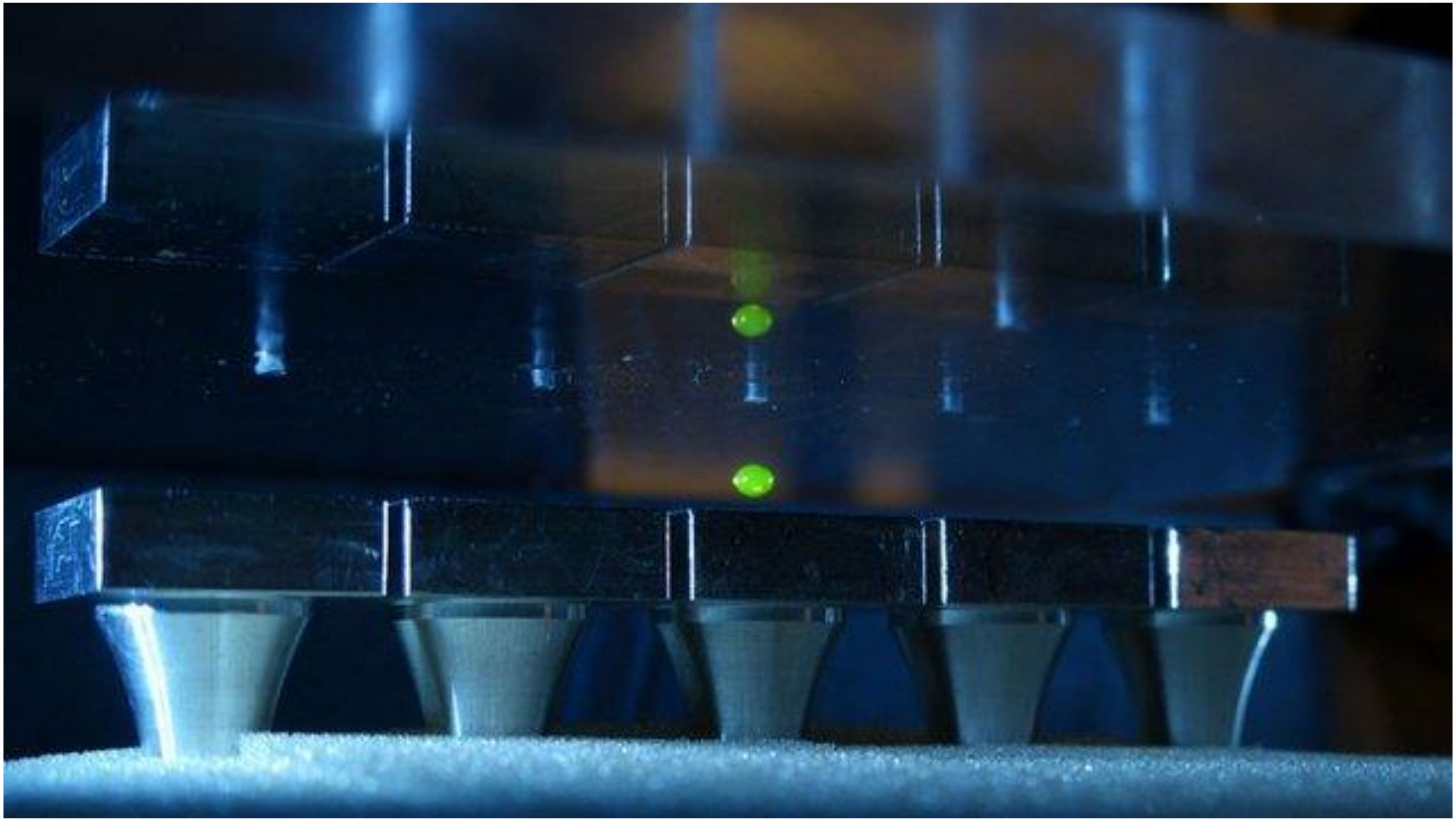
- It is being used for container less processing.
- Used for applications requiring very-high-purity materials or chemical reactions too rigorous to happen in a container.
- This method is harder to control than other methods of container less processing such as electromagnetic levitation but has the advantage of being able to levitate non-conducting materials.
- Physicists at the Argonne National Laboratory are using sound waves to levitate individual droplets of solutions containing pharmaceuticals in a bid to improve drug development.

Reaction between Sodium and Water

[Video]

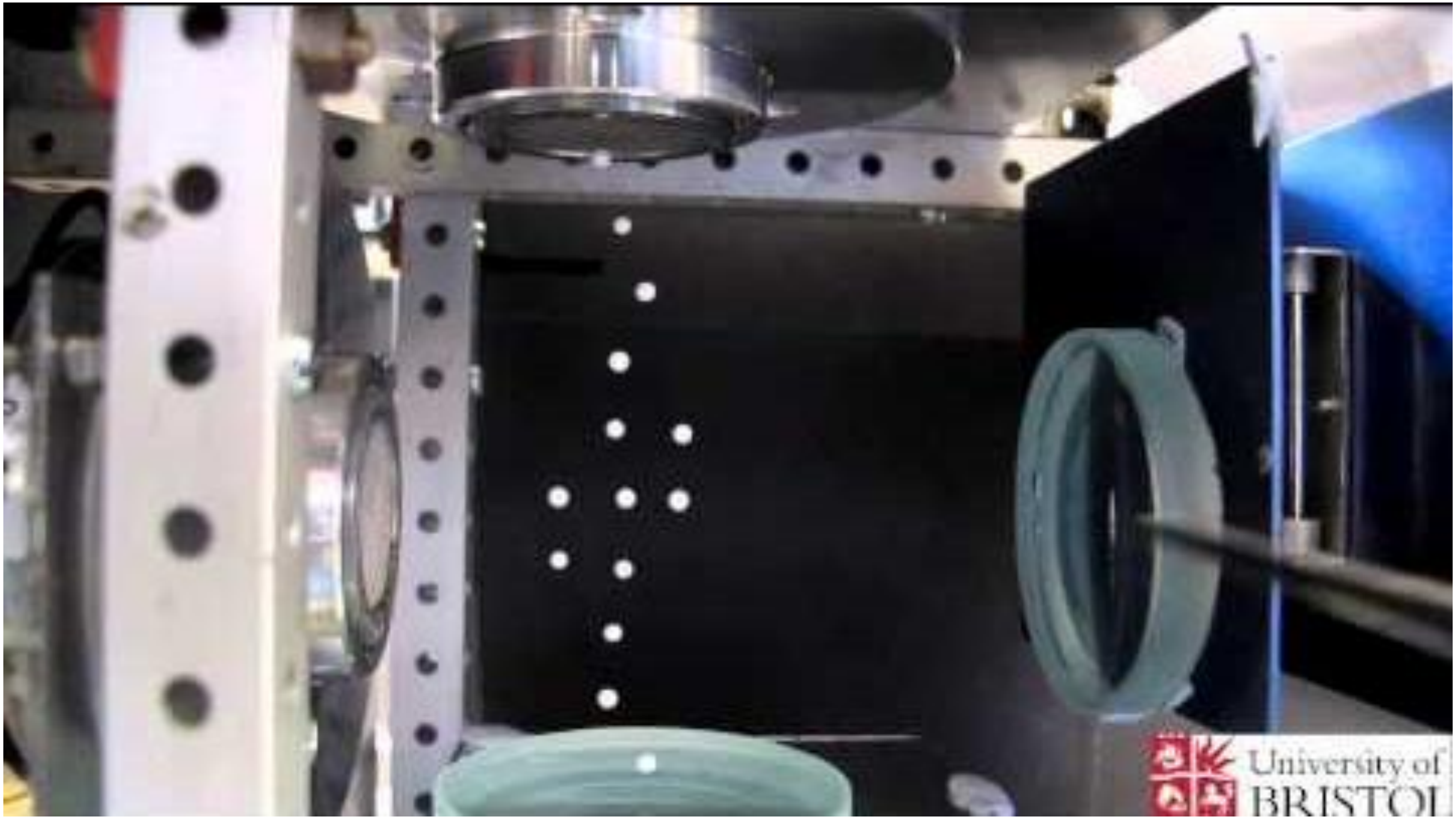
Current Resonating Machines

Current Resonating Machines



Current Resonating Machines

Current Resonating Machines



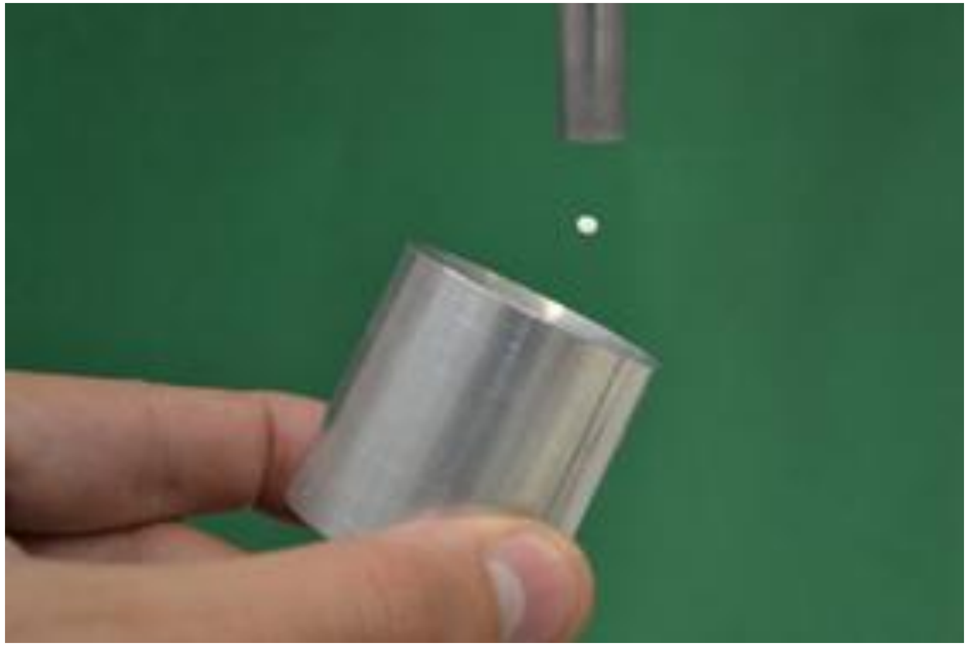
Three dimensional acoustic levitator

Developed by:
落合陽一(東京大学)
星貴之一(名古屋工業大学)
暦本純一 (東京大学)

Three dimensional acoustic levitator

Developed by:
Yoichi Ochiai ー(The University of Tokyo)
Takayuki Hoshiー(Nagoya Institute of Technology)
Jun Rekimoto ー(The University of Tokyo / Sony CSL)

Video



Particle manipulation by a non-resonant acoustic levitator

Authors:

Marco A. B. Andrade, Nicolás Pérez and Julio C. Adamowski

Author affiliations:

University of São Paulo in Brazil and Universidad de la República in Uruguay

Particle Manipulation by non-resonant levitator

- University of São Paulo researchers have developed a new levitation device that can hover a tiny object with more control than was previously possible.

- Featured on the January 2015 cover of the journal Applied Physics Letters in an open-access paper, the device can levitate polystyrene particles by reflecting sound waves from a source off a concave reflector below.

Particle Manipulation by non-resonant levitator

- Other researchers have built similar devices in the past, but they always required a precise setup where the sound source and reflector were at fixed "resonant" distances. This made controlling the levitating objects difficult.

- The new device shows that it is possible to build a "non-resonant" levitation device -- one that does not require a fixed separation distance between the source and the reflector.

Concept

- In resonant levitators a standing wave is formed by the multiple wave reflections that occur between the transducer and the reflector placed at a fixed distance.
- In this non-resonant levitator the standing wave is formed by the superposition of two waves; the emitted wave by the transducer and first reflected wave.
- This interference creates a pressure node near the surface of the reflector where the small particle is levitated.

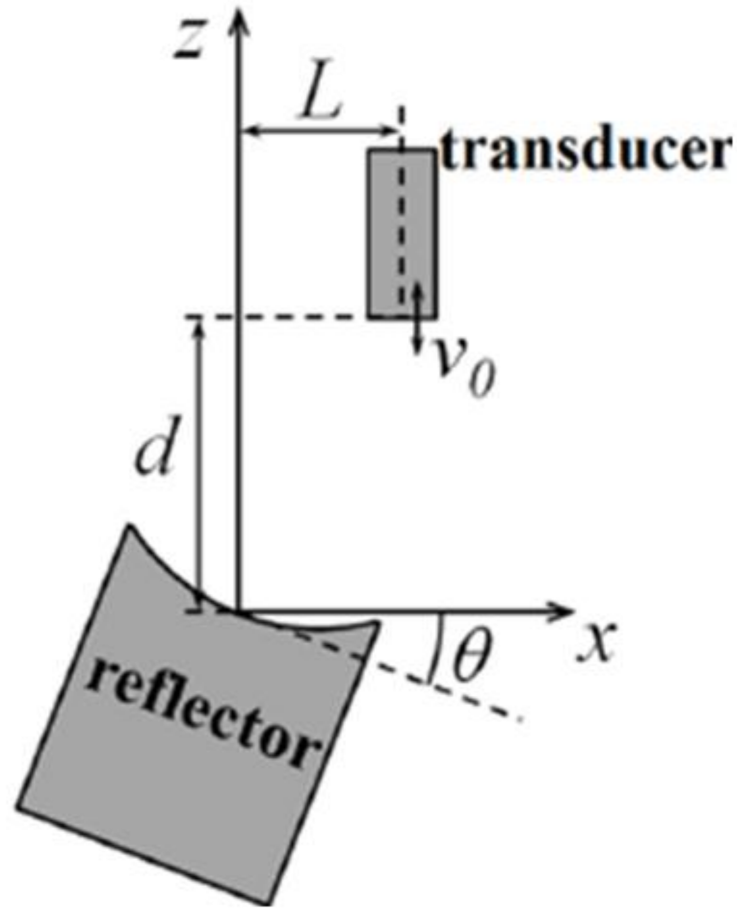
Concept

- A standing wave can also be generated by the superposition of counter-propagating waves emitted by two opposed transducers.
- In this the nodal position can be controlled by changing the phase difference between the two transducers.

Hardware & Construction

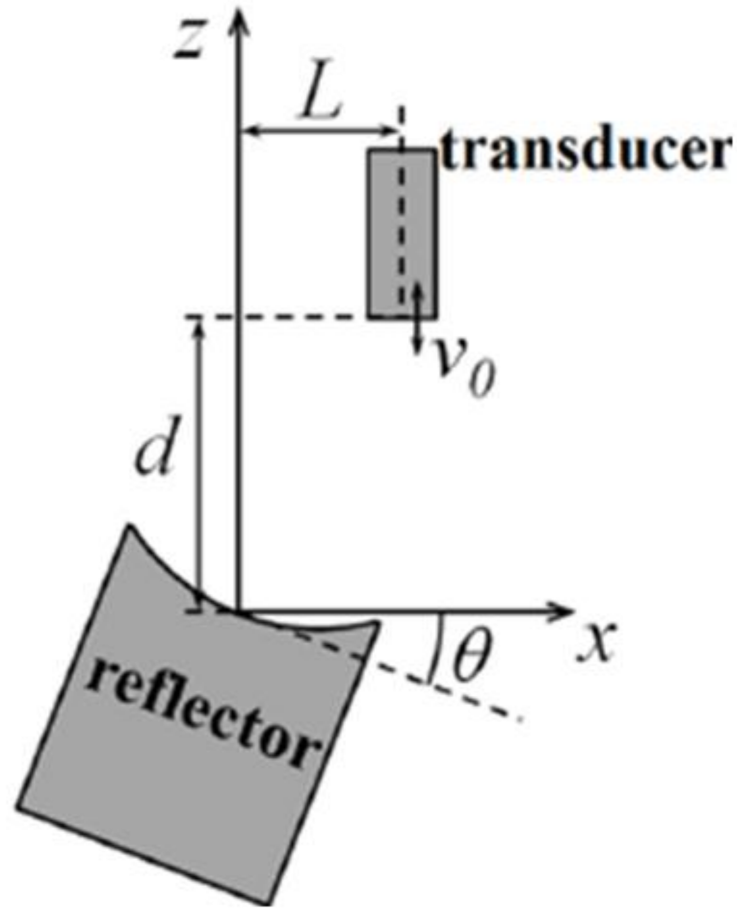
- A piezoelectric transducer with a flat vibrating surface of 10mm diameter. It vibrates with frequency of 23.7kHz approximately with an amplitude Vo

- A Concave reflector of 40mm diameter with a curvature radius of 33mm.



Hardware & Construction

- Distance between the transducer and reflector is represented by “d”.
- Reflector can be displaced off by axis by a distance of “L” and can even be titled by an angle “Θ”.



Mathematical models

- To understand the levitator behavior following two methods were used:

1. Matrix method based on the Rayleigh integral to simulate the wave propagation inside the levitator.
2. Gor’kov theory to calculate the potential of the acoustic radiation force that acts on a small sphere.

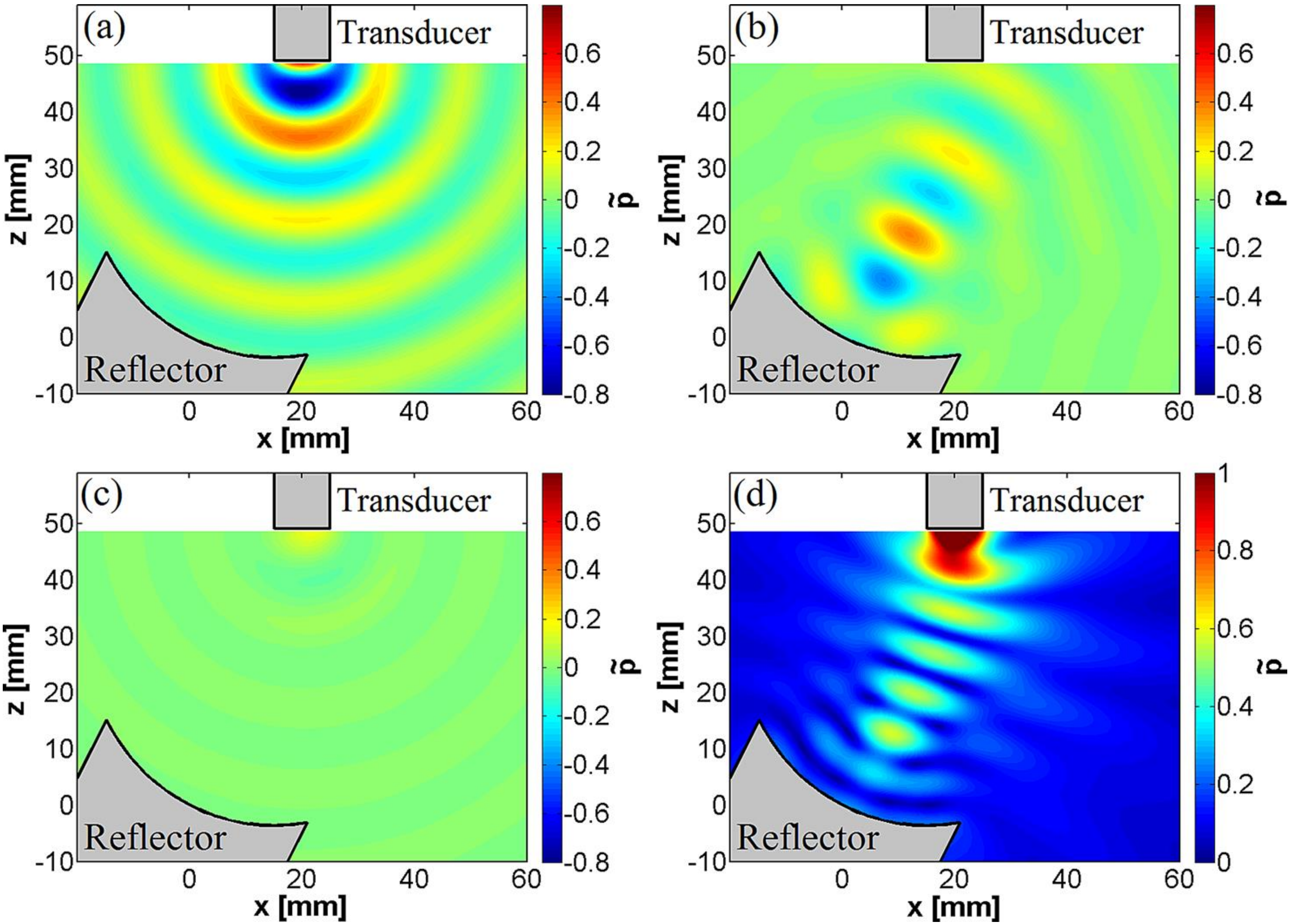
Mathematical models

Matrix Method

- The matrix method was applied to simulate the wave propagation inside the levitator.
- In this method, the pressure distribution is determined by summing the multiple wave reflections that occur between the transducer and the reflector.
- The dimensionless form of pressure was used

$$\tilde{p} = \frac{p}{\rho c v^{\circ}}$$

$$\begin{aligned}
&air\ density && \rho\ = 1.2kg/m\hat{}3 \\
&sound\ velocity && c\ = 340\ \mathrm{m/s} \\
& && v^{\circ} = Velocity\ amplitude\ of\ transducer
\end{aligned}$$



(a)
Transducer
Reflector
(b)
Transducer
Reflector
(c)
Transducer
Reflector
(d)
Transducer
Reflector
z [mm]
x [mm]
p̃

Mathematical models

Matrix Method

- In figure(a) The first emitted wave from the transducer is simulated.
- Figure(b) shows the pressure after the first reflection.
- Figure (c) shows the wave after the second reflection.
- And Figure (d) shows the modulus of the dimensionless pressure which corresponds to the sum of the three previous waves.

Mathematical models

Matrix Method

- In this setup we can see from Figure (d) that only 3% of the total energy is reflected back to the transducer surface.
- This is due to the small diameter of the transducer, the first reflected wave is almost completely spread into the surrounding medium and only a small portion is reflected back.

Mathematical models

Matrix Method

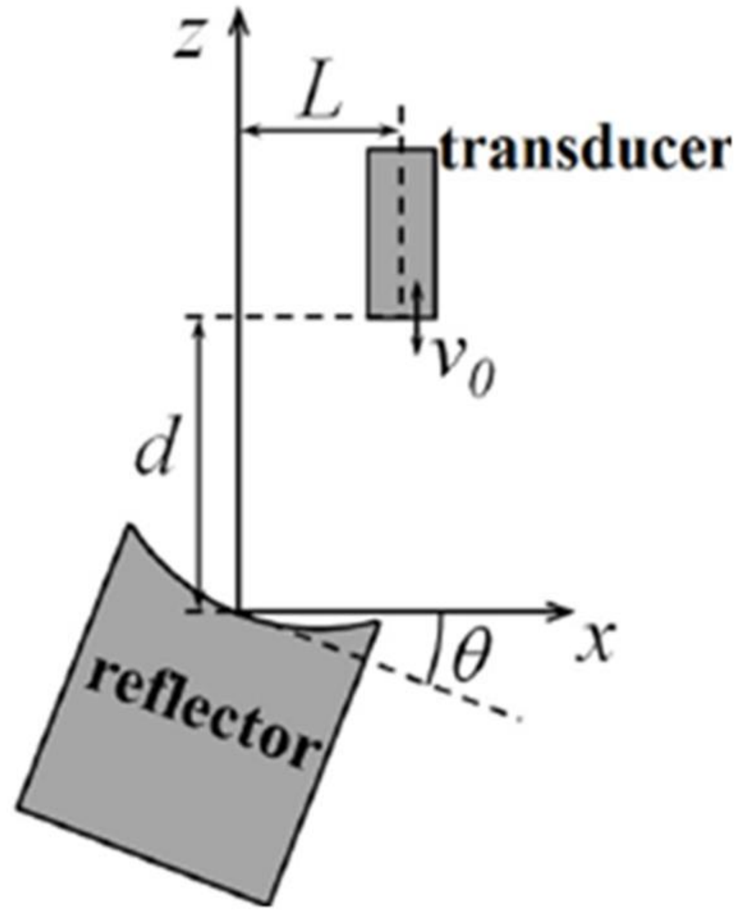
- In this condition, we can consider that the standing wave is formed by the superposition of the emitted wave and the first reflected wave.

- Another consequence of the small transducer radius is that the emitted wave is almost spherical which means that the reflector can be tilted and displaced off-axis.

Mathematical models

Gor’kov Potential

- After obtaining the acoustic pressure distribution by the matrix method, Gor’kov potential was used for different values of d, L and ϴ.



Mathematical models

Gor’kov Potential

- According to Gor’kov theory acoustic radiation force produced by a standing wave that acts on a sphere with a size much smaller than the wavelength can be calculated from the Gor’kov potentual *U* given by,

$$U = 2\pi R^3 \left[\frac{\langle \rho^2 \rangle}{3\rho c^2} - \frac{\rho \langle u^2 \rangle}{2}\right]$$

where,

R = the radius of the sphere

ρ = air density

c = sound velocity in air

$\langle \rho^2 \rangle$ *= mean square amplitudes of the sound pressure*

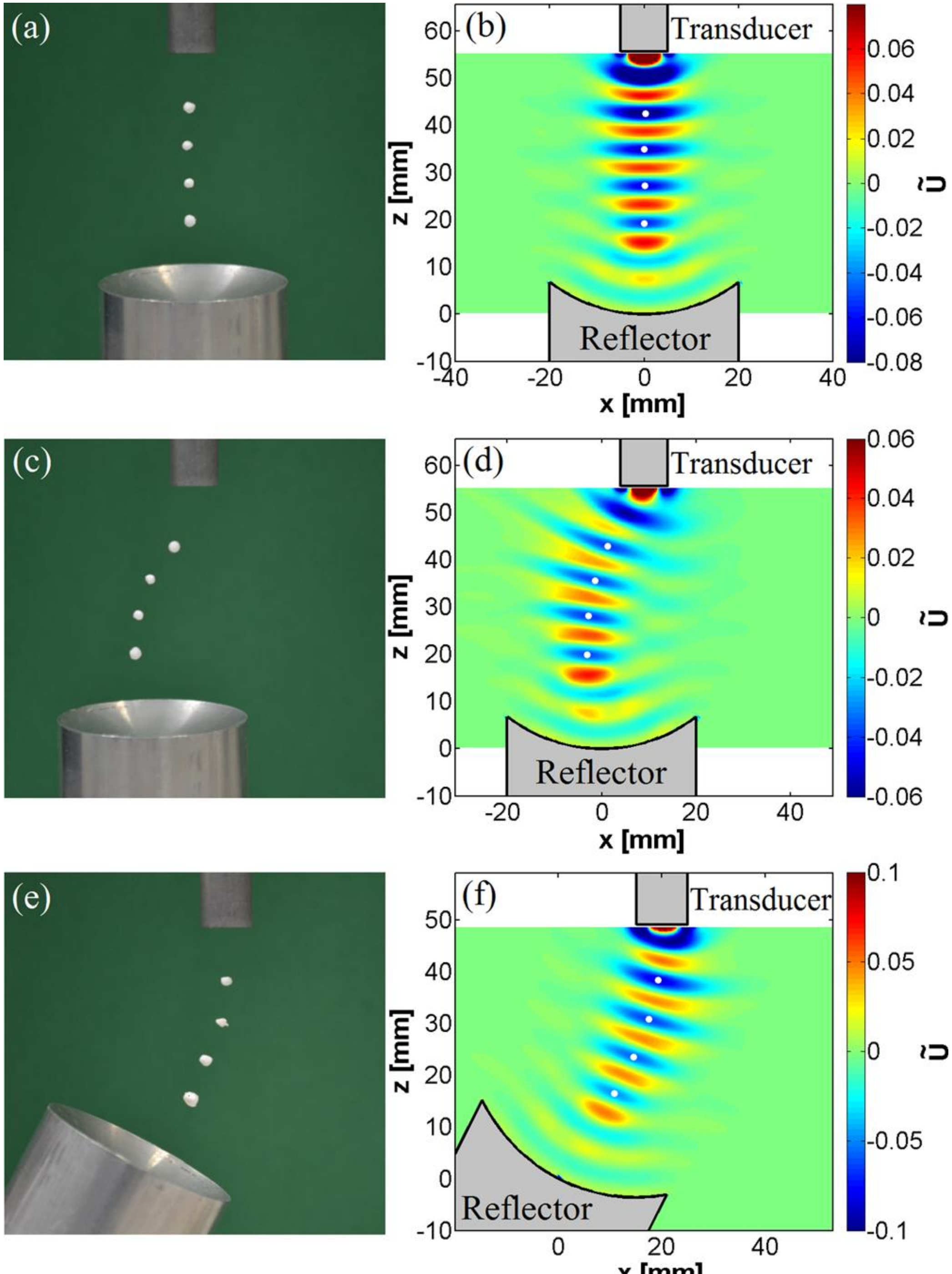
$\langle u^2 \rangle$ *= mean square amplitudes of sound velocity*

Mathematical models

Gor’kov Potential

- But for this article they have used the dimensionless form of the Gor’kov potential given by,

$$\widetilde{U} = \frac{U}{2\pi R^3 \rho v}$$



For Configuration:
D= 55.7mm, L=0, and Θ=0˚

For Configuration:
D= 55.7mm, L=9mm and Θ=0˚

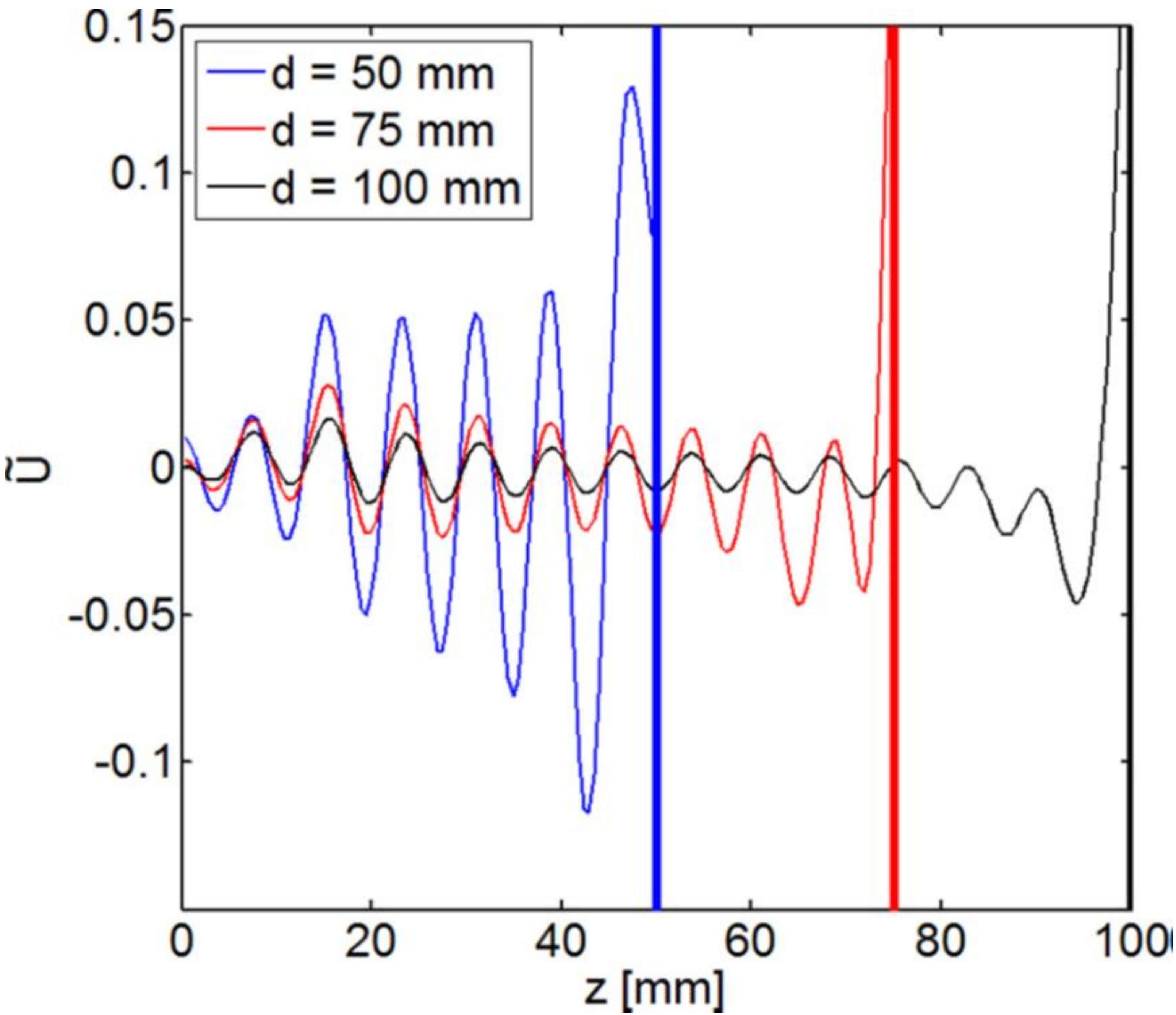
For Configuration:
D= 49.0mm, L=20mm, and Θ=27˚

Mathematical models

Gor’kov Potential

- The methods were also applied to investigate the influence of the separation distance between the transducer and the reflector on the acoustic radiation force that acts on the levitated particle.

- In this analysis, L and Θ were set to zero and the Gor’kov potential along the z-axis for d=50mm, 75mm and 100mm was tested.


d = 50 mm
d = 75 mm
d = 100 mm
0.15
0.1
0.05
0
-0.05
-0.1
Ũ
0
20
40
60
80
100
z [mm]

Particle Manipulation by a non-resonant levitator

Video

Conclusion

- Single-axis acoustic levitation where the separation distance between the transducer and the reflector can be adjusted continually without requiring the distance to be carefully adjusted to match a resonance condition.

- The levitator behavior was analyzed by using a numerical model that combines a matrix method based on the Rayleigh integral with the Gor'kov theory.

- The numerical simulation showed us that the standing wave in this case is basically formed by the superposition of two traveling waves: the emitted wave by the transducer surface and the reflected wave.

Furthermore

- We could develop a laboratory experiment out of the acoustic levitator machine where students could be introduced to this concept.
- A sample experiment in this regard is available which can be used as a reference.

Thank You!
Any questions???