Oscillating Small Particles in Gor'Kov Potential

Wei-Cheng Hong(洪偉晟), Chih-Hsiang Yeh(葉智翔)
TA: Ssu-Yuan Lin(林思遠), Instructor: Chien-Jung Lo(羅健榮)
Department of Physics, National Central University, Taoyuan, Taiwan

Abstract

Ultrasonic transducers can levitated objects. The levitating force is determined by the Gor'Kov potential. We can manipulate particles in ultrasonic field by controlling the potential landscape.

Introduction

Sound is a mechanical wave that can generate acoustic radiation force. Particles in sonic field can be levitated against gravity when the forces are strong enough and converge. We can also generate some phase shift to change the pressure strength to make the particles transport between two local Minimums in the field. However, most important thing for the particles transportation is phase shift. It can be accomplished by traveling distance difference and time delayed signal to the emitters. The Gor'Kov potential U is :

$$U(\vec{r}) = K_1(|P|^2) - K_2\left(|P_x|^2 + |P_y|^2 + |P_z|^2\right) - (1)$$

The force comes from do the gradient operation to the potential, the force can be derivated from eq.(1):

$$F_{ultrasonic\ ratiation}(\vec{r}) = -\nabla U(\vec{r}) - (2)$$

The complex pressure P at point $\vec{r}$ due to a piston source emitting at single frequency can be modeled as:

$$P(\vec{r}) = P_0 A\left(\frac{D_f(\theta)}{d}\right)e^{i(\phi + kd \pm \omega t)} - (3)$$

For N piston sources in the same plane the pressure can be consider as the interference of sound waves the Pressure field can be expressed as a summation of all sources :

$$P(\vec{r}) = \sum_{n=0}^{N} P_n A_n\left(\frac{D_f(\theta_n)}{d_n}\right)e^{i(\phi_n + kd_n \pm \omega t)} - (4)$$

Where P_n is the output power from transducers, A_n is input voltage, ϕ_n is the phase shift modulated by the electric signal.The potential field(eq.(1)) can be constructed by the pressure field(eq.(4)). We can use the eq.(4) to give the Field a simply look.
We simulate the Pressure from eq.(4). The ideal field for three transducer pairs, which center is located at (0,-0.01,0), (0,0,0), (0,0.01,0), as show in Fig.1. The middle one with $1/2\pi$ phase shift, the ideal field as show in Fig.2

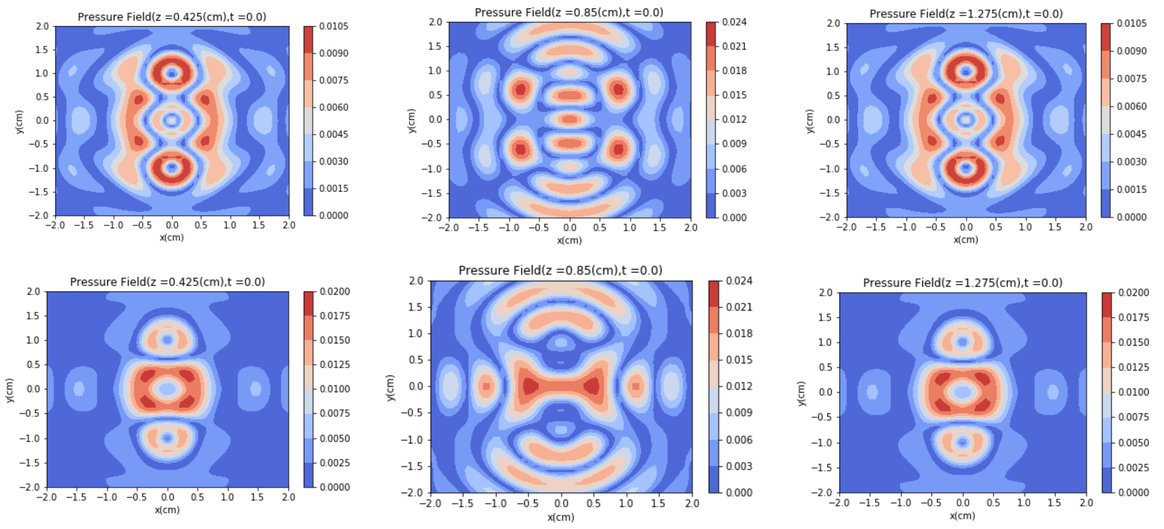

Fig.1(up) , Fig.2(down) the simulation of ideal field from eq.(4)

Experiment Setup

We use ultrasonic transducers(MA40S4S) to built the field. The best working frequency is 40kHz and input voltage is 16Vpp. We use two array like elements with opposite direction to enhance the levitating force. The distance of the arrays is approximate to 1.7cm. We use three transducer pairs, and give them different frequency to make a phase shift between the transducer pairs. We put a camera to track the particle trajectory in field. The particles we used is Styrofoam the diameter and density is 2-3mm, 0.032(mg/mm^3). The schematics of the experiment setup as show in Fig.3

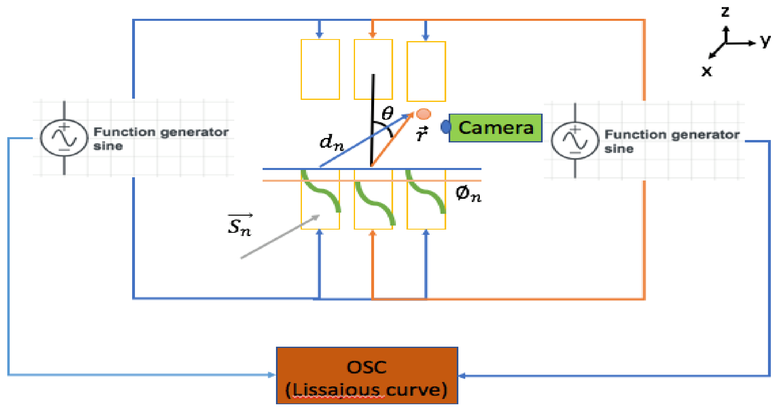

Fig.3 the schematics of experiment setting

Result

We use three different periodic shifting phase, measure the trajectory in x ,z direction. We can find the particle in the field will move corresponding to the periodic signal. We use image processing to analysis the trajectory of the particle and the intensity of RGB color to measure the Lissajous curve changing rate.

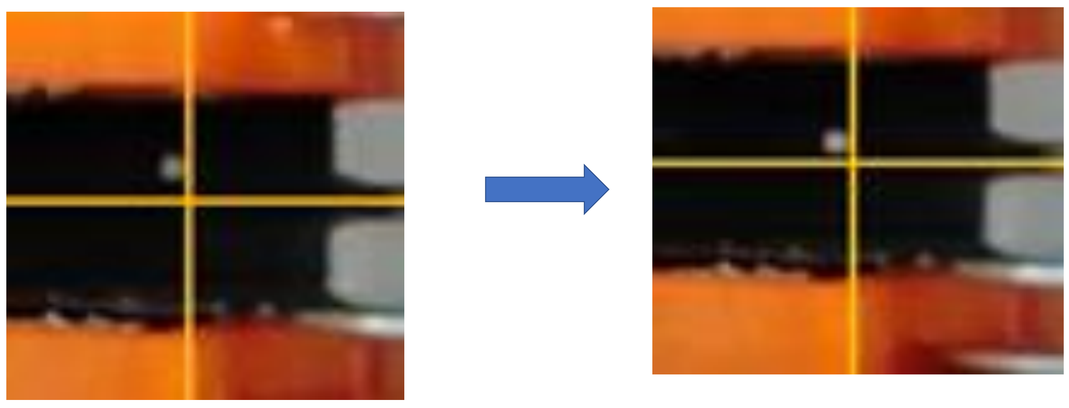

Fig.4 the particle transport by the Pressure Field

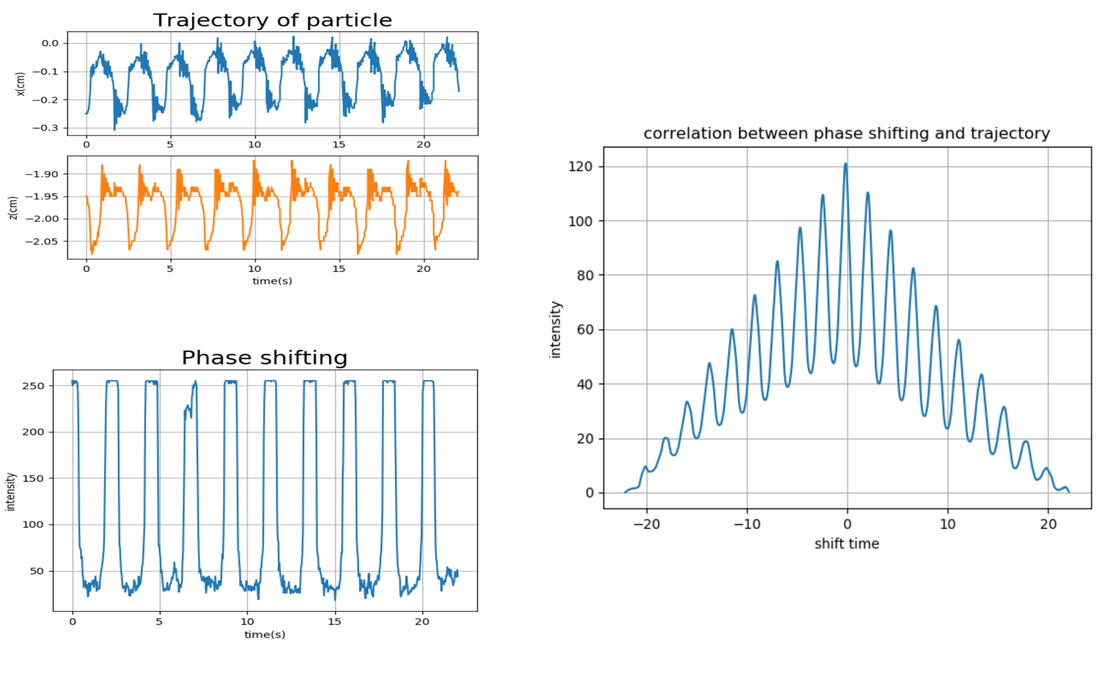

Fig.5 the trajectory of particle under the period of shifting phase is 2s.

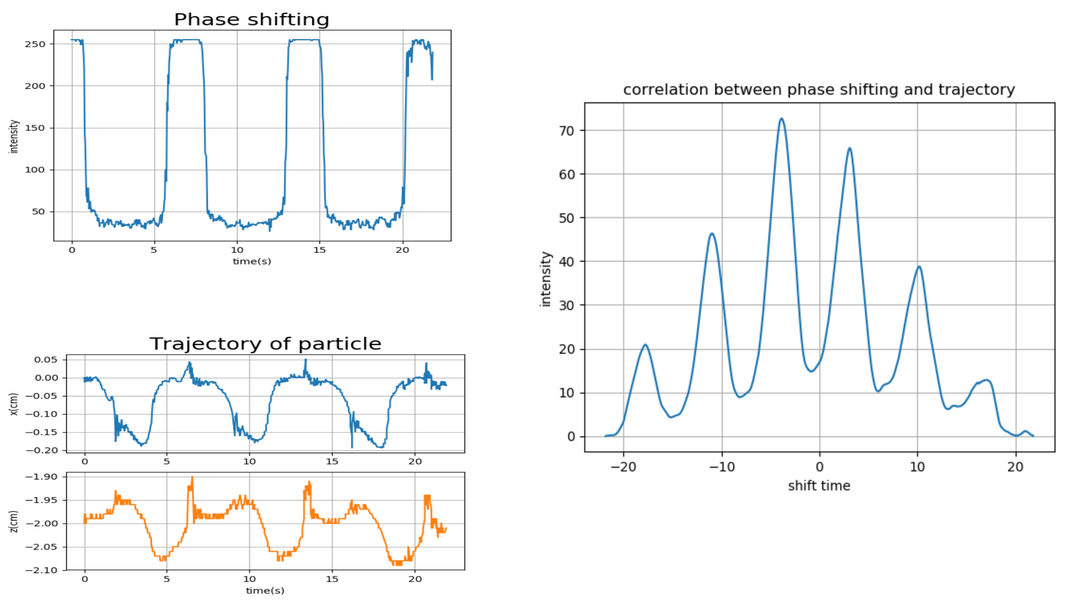

Fig.6 the trajectory of particle under the period of shifting phase is 7s.

Conclusion

1. The Gov'Kov potential(pressure field of sound wave) is sensitive to the phase, the phase can come from the propagating distance, passing time and signal modulation, if we can control the phase well we can make the a good transportation.

Reference

1. "Ultraino: An Open Phased-Array System for Narrowband Airborne Ultrasound Transmission" by Asier Marzo at 2018.
2. "Holographic acoustic elements for manipulation of levitated objects" by Asier Marzo at 2015.