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## Control of ordered group of particles based on ultrasonic levitation

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# Control of ordered group of particles based on ultrasonic levitation

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**Abstract.** A method is proposed for controlling a group of particles under conditions of ultrasonic levitation in air. The possibility of placing particles in a stack of nodes of standing waves in a given order using a system of phased arrays of ultrasonic emitters is considered. Flat phased arrays are placed on the sides and on top of the levitation area. The side arrays create a plane in which the levitation of particles in an ordered grid is arranged. The top and bottom lattice ensures the placement of particles in an arbitrary order within the plane. The results of numerical simulation are presented.

## 1. Introduction

A control of particles in the conditions of ultrasonic levitation is necessary for a number of practical applications, such as levitation chemical reactors, soldering, fusion and coagulation. It is possible to calculate the particle trajectory under the action of a traveling ultrasonic field based on Newton's laws, and controlling the phase and amplitude of the wave, specify the desired acceleration vector for the particle. However, the further trajectory of the particle essentially depends on the friction forces, turbulent flows, temperature gradients. As a result, the behavior of the particle becomes poorly predictable. It is advisable to create a potential well for a particle at a given point in space, and then by moving the region of minimum potential to ensure controlled particle motion. The position of the particle in the potential well should be stabilized due to the friction force. As a function of the potential, it is suitable to apply the Gor'kov potential [1, 2].

In [3] authors proposed to use a combination of acoustic force and acoustic streaming. Side emitters are used to form a Cartesian grid of standing waves for arranging particles in a liquid. In this case, the emitters operated at the same frequency. They have shown an ability of proposed system to pattern for medium and large size particles.

Ultrasonic levitation technologies based on vertically emitting sources of plane waves, such as the near field [4] and in the far-field emitters [5, 6], are most widely used. The use of reflectors of the focusing form [5] allows localizing the region of levitation along horizontal axes. In a standing wave, it is possible to levitate particles up to 1/3 of a wavelength [5]. Researchers from the Polytechnic University of San Paulo, Brazil [7], by optimizing the shape and placement of the emitter and reflector, provided the levitation of steel balls in the ultrasonic field of standing waves. Later, they managed to provide levitation in a non-resonant mode on a standing wave formed by a single reflection from a focusing reflector [8]. Particles under the action of the sound field can not only move into a stable position, but also rotate at a given speed, as was shown in [9]. The control of particles in a standing wave by irradiating a flat reflector with the field of a phased array is shown in [10]. However, this approach does not allow arbitrary manipulation of particles along the vertical axis and does not

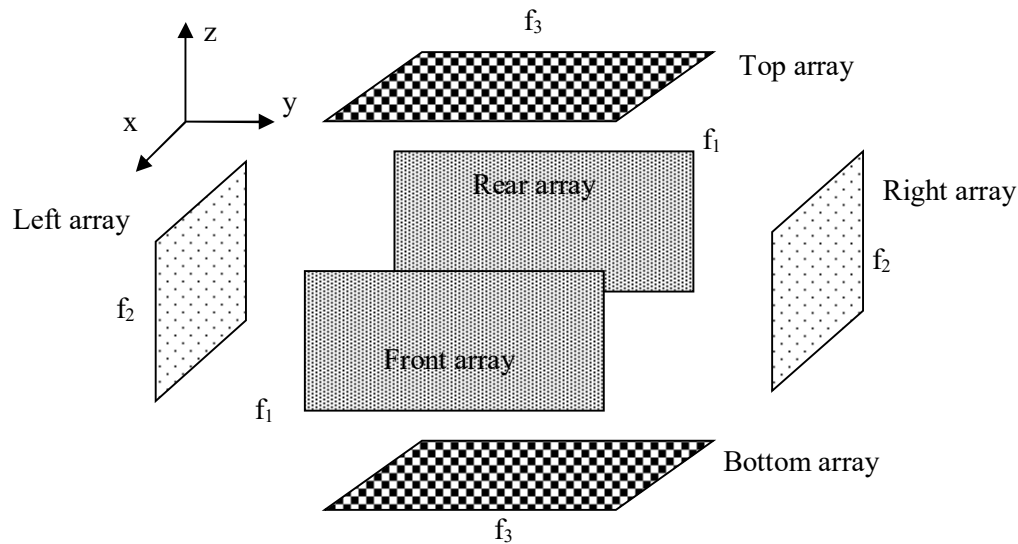


allow the formation of raster images by particles. Theoretically forces acting on levitating spherical particle in an ultrasonic standing wave has been investigated in [11].

Here we propose to apply the ultrasonic fields at different frequencies to control the position of the particle in three-dimensional space. The difference in the frequencies of the radiators oriented orthogonally allows us to obtain more stable conditions for the levitation of particles. Changing the phase relationships of counter emitters provides control of a group of particles in three-dimensional space.

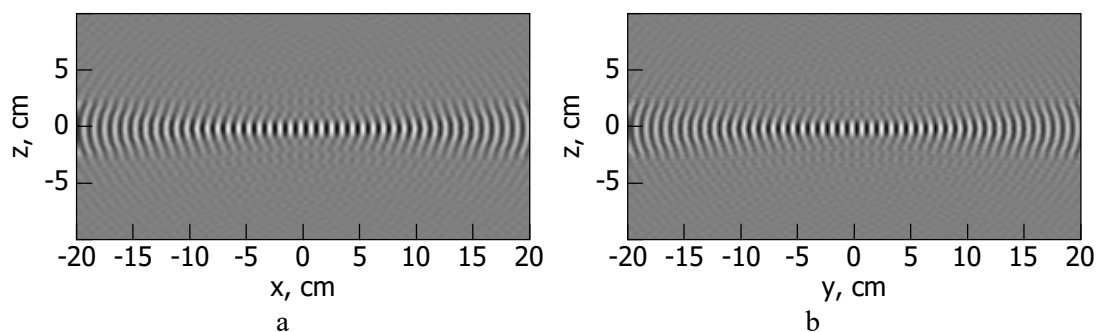
## 2. System overview

The layout of the emitters is shown in Figure 1. It is proposed to apply 6 plane phased array emitters: two oppositely directed emitters for the X, Y and Z axes. The X-axis emitters operate at frequency  $f_1$ , the Y-emitters at  $f_2$ , and the Z-emitters at  $f_3$ . Counter-emitters of waves at the same frequency create standing waves, and levitating particles are grouped into pressure nodes of standing waves [3].



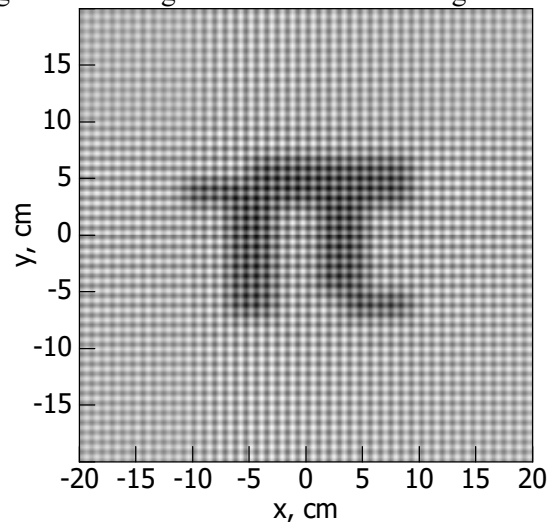
**Figure 1.** Placement of phased arrays.

It is proposed to focus left, right, front and rear phased arrays at by Z axis the center of system, but not localized horizontally (Figure 2). Such fields from horizontal grids of standing waves that form a rectangular area of levitation with potential holes in a periodic Cartesian grid. In total, with fields from phased arrays radiating in a vertical direction (top and bottom arrays), a field is formed that provides a given pattern of placement of particles (Figure 3).



**Figure 2.** Field of horizontally radiating arrays (a – left and right arrays field at frequency 38 kHz, b – Front and rear arrays field at frequency 40 kHz).

The field of the upper and lower phased arrays form the image of the Greek letter “ $\pi$ ” by focusing the field on the levitation plane at a frequency of 22 kHz. It is assumed that the particles will be grouped into the maximum field and repeat the shape of the specified image. To prevent particles from gathering at local maxima inside the image, the fields of the side grids form a rectangular grid that prevents particles from moving inside homogeneous areas of the image.



**Figure 3.** Sum of all arrays field forming an image of letter “ $\pi$ ”.

Oriented orthogonally grids emit at different and non-multiple frequencies to increase the stability of levitation of particles in an ultrasonic field. Numerical modeling shows that if frequencies are the same the behavior of particles is not stable.

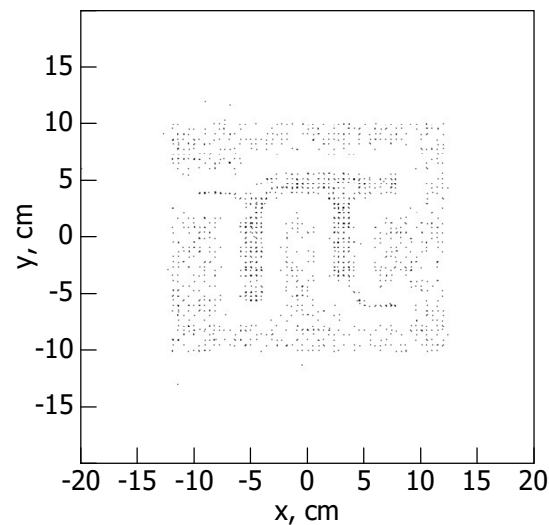
### 3. Numerical simulation of particles levitation

We conducted a numerical simulation of levitation in an ultrasonic field in the air for Styrofoam particles with a density of  $15 \text{ kg/m}^3$  with a diameter from 400  $\mu\text{m}$  to 600  $\mu\text{m}$ . The modeling was carried out on the basis of the Newton's motion equations, the Gor'kov formula [1] for taking into account the force of acoustic pressure. Also the friction force in air for spherical particles has been and taken into account. The initial distribution of particles was set randomly on a flat rectangular area of 20 cm by 20 cm. As a result of the simulation, it was found that after 100 ms the position of the particles stabilized in accordance with the specified field distribution (Figure 4).

According to the results of numerical simulation, one can see that the particles have stabilized in a given figure. By changing the phase ratio of the left and right gratings of the emitters, all structures are moved along the x axis. A change in the phases of the front and rare arrays allows you to move the structure along the y axis. Similarly, changing the phase difference top and bottom arrays allows you to move the structure along the vertical axis. Moving should occur, so that the particles have time to stabilize in the new position. Numerical simulation shows that the speed should not exceed, for the case under consideration, the value of 20 mm/s.

The side emitters ensured the formation of a grid of local field maxima in a Cartesian grid with a period of about 4 mm. Particles cannot pass from one local minimum to another unless sufficient radiation is applied from the upper and lower lattice. The upper and lower lattices form the required image of a layer of levitating particles. In the field of the gradient change of the field of vertical emitters, a sufficient force arises for the rearrangement of particles and the formation of the required stable image.

Not all particles have shifted to a given region of maximum field, since the potential gradient exists only near intensity changing regions. To displace all particles into the required image area, it is necessary to change the field of the upper and lower phased grids so that the field gradient piecemeal moves the particles into the area of the required image.



**Figure 4.** Stabilized Styrofoam particles distribution while levitating in air by influence of ultrasonic field (numerical simulation).

#### 4. Conclusions

A method is proposed for controlling an ordered group of particles in ultrasonic levitation in air. It is proposed to provide levitation of particles in the Cartesian grid by creating a field of standing waves from orthogonal phased arrays emitting at different frequencies. The control of the fields of phased lattices allows you to create areas of stable levitation of particles of a given shape. The change in the phase relations of the counter lattices allows one to move ordered groups of particles along three orthogonal axes.. The results of numerical simulation on the formation of a flat bitmap image of levitating particles are presented.

#### Acknowledgments

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