Layer-by-layer application of particles using acoustic levitation

D Sukhanov1, S Roslyakov2 and F Emelyanov3
1Professor, Radiophysics Faculty, Tomsk State University, Tomsk, Russia
2PhD student, Radiophysics Faculty, Tomsk State University, Tomsk, Russia
3Student, Radiophysics Faculty, Tomsk State University, Tomsk, Russia
E-mail: sdy@mail.tsu.ru

Abstract. A method of layer-by-layer deposition of particles on a flat surface using acoustic levitation in air is proposed. An acoustic field for particle levitation is created using four phased emitter arrays. A field distribution is created that ensures the levitation of particles in a flat layer in a rectangular grid. Using a sound-transparent mesh, particles are fed into the levitation area. The use of an additional focused lattice makes it possible to remove excess particles from the levitation region. Particles are deposited by refocusing the side gratings to a lower height, followed by turning off the field.

1. Introduction
A number of technological processes have the task of applying particles to the surface [1]. For example, for additive manufacturing technologies [2, 3]. The technology of layer-by-layer powder deposition with subsequent selective sintering or chemical curing is widespread in modern additive manufacturing. However, not all materials are suitable for powder printing. In order to expand the list of possible materials for powder printing, it is necessary to develop other methods for applying particles. Currently, methods of acoustic levitation [4] and control of particles suspended in the air by an ultrasonic field are being intensively developed [5–11].

It is proposed to realize layer-by-layer deposition of powder materials on flat surfaces using acoustic levitation in air. The levitation of particles in a flat layer is ensured using four counter-array emitters focused in a common plane [6]. Due to the occurrence of standing waves by interference of the fields of the opposing gratings, the levitation of particles in a rectangular grid is ensured. The use of the upper lattice of ultrasonic emitters allows you to build particles in the required order. It is proposed to use a mesh sound-transparent conveyor for feeding particles and removing excess particles from the levitation area.

2. Particle deposition by acoustic levitation method
Consider an acoustic levitation device based on four phased emitter arrays (Figure 1). To increase the stability of levitation and control the grid pitch of levitating particles, it is possible to use different frequencies for signals of different counter-gratings.
Each emitter array is focused in a line that is parallel to the array and in a horizontal plane at a given height. The focus line is chosen the same for opposite lattices and passes in the middle between them. When the fields of the opposing gratings are interfered, standing waves arise at the sites that group the levitating particles [6]. As a result, the particles are ordered and levitate in a rectangular grid in a square region. By adjusting the phase difference of the opposing gratings, it is possible to perform the movement of the nodes of standing waves, and, therefore, levitating particles in the horizontal plane. The vertical movement of particles is ensured by refocusing the gratings to a different height.

It is proposed to introduce particles into the area of acoustic levitation using a special mesh conveyor. This will minimize their disordered application. The mesh conveyor has gaps for the unimpeded transfer of particles by the ultrasonic field. It is proposed to supply particles using a mesh conveyor for 6 cycles:

1) Filling the particles onto the mesh tape (Figure 2).

2) Raising particles from the mesh tape using the ultrasonic field of the side arrays (Figure 3). In this case, part of the particles that are outside the field of action of the field or particles of irregular shape remain on the tape - this is how the problem of rejecting particles and minimizing clogging of the levitation region is solved.

3) Then, using the upper phased array of ultrasonic emitters, unnecessary particles are knocked out of the cloud of levitating particles by an ultrasonic field and the required image of the particle layer is formed to form the corresponding three-dimensional object. Embossed particles settle on the mesh belt along with the rejected particles.

4) Removal of rejected particles by the conveyor on the mesh belt with the support of levitation of ordered particles (Figure 4). After completing this operation, the conveyor in the levitation area is moved to correspond by the opening in the mesh belt, so that the particles can freely move in the levitation area.

5) Moving levitating particles using side emitters under a mesh conveyor to the infrared heating region of the particles before applying them to the formed three-dimensional object (Figure 5).

6) Precipitation of heated particles on a substrate and their fixing.
3. Experimental study
An experiment was conducted to install particles in the levitation region using a mesh surface (Figure 6). The experiment showed that it is possible to ensure the introduction of particles into the levitation region on the grid and the lifting of particles from the grid using lateral emitters of the ultrasonic field.

Figure 2. The use of a mesh conveyor for feeding particles into the area of acoustic levitation: Filling particles onto a mesh belt

Figure 3. The use of a mesh conveyor for feeding particles into the area of acoustic levitation: Lifting particles from a mesh belt using the ultrasonic field of the side gratings

Figure 4. Removal of rejected particles by the conveyor while supporting ordered particles levitation

Figure 5. Moving levitating particles using side emitters under the mesh conveyor to the infrared heating region of particles before applying them to the formed three-dimensional object

Figure 6. The introduction of particles into the levitation region using a mesh surface: a – focusing the field at the grid level; b – focusing the field above the grid level
An experiment was conducted on the deposition of particles on the surface using lateral emitting gratings (Figure 7). To fix the foam particles on the substrate, fleecy fabric was used. When the field was refocused smoothly to the substrate level, the particles gradually precipitated, however, due to inaccuracies in the sensor calibration, the generated field does not completely coincide with the calculated one, which caused some particles to be removed from the levitation region during field refocusing. Nevertheless, most of it settled on the substrate in accordance with the order established in the process of levitation.

![Figure 7. An experiment on the deposition of levitating foam particles on a fleecy surface:](image)
a – particles levitate in an ultrasonic field, b – deposition of particles on a fleecy fabric

Particles line up in a rectangular grid in increments of a quarter of the wavelength. To form a filled image, it is necessary to repeat the deposition of particles on the same layer several times, shifting each subsequent layer with a certain step.

### 4. Conclusions
A method for applying particles to a flat surface using acoustic levitation is proposed. Based on the side emitter lattices, a flat levitation layer is provided with particles placed in a rectangular grid. The supply of particles and the removal of excess particles is carried out using a sound-transparent mesh conveyor. It has been experimentally shown the possibility of such a method of applying particles using an example of foam particles.

### Acknowledgments
The scientific research was carried out with the support of the grant of the Russian Science Foundation No. 17-79-20051.

### References
[1] Gor’kov L P 1962 Sov. Phys. Dokl. 6(9) 773–775
[2] Baresch D, Thomas J L, Marchiano R 2013 The Journal of the Acoustical Society of America 133 25 doi:10.1121/1.4770256
[3] Liu S, Yang Y, Ni Z, Guo X, Luo L, Tu J, Zhang D, Zhang A J 2017 Sensors 17 1664 doi: 10.3390/s17071664
[4] Li J, Liu P, Ding H, Cao W 2011 IEEE International Conference on Robotics and Automation 12288561 doi: 10.1109/ICRA.2011.5979642
[5] Zhang F, Jin Z 2018 Open Access Library Journal 05 doi: 10.4236/oalib.1104948
[6] Andrade M A et al 2011 IEEE Transactions on Ultrasonics Ferroelectrics and Frequency Control 58(8) 1674 – 1683 doi: 10.1109/TUFFC.2011.1995
[7] Marco A. B. Andrade, Flavio Buiochi, Julio C. Adamowski 2010 IEEE Transactions on ultrasonics, ferroelectrics and frequency control 57 469–479 doi: 10.1109/TUFFC.2010.1427
[8] Andrade M A B, Buiochi F, Adamowski J C 2015 Physics Procedia 70 68–71 doi:10.1016/j.phpro.2015.08.044
[9] Hong Z Y et al 2017 Sci Rep. 7 7093 doi: 10.1038/s41598-017-07477-1
[10] Watanabe A, Hasegawa K, Abe Y 2018 Scientific Reports 8 10221 doi:10.1038/s41598-018-28451-5
[11] Barrios G, Rechtman R 2008 Journal of Fluid Mechanics 596 191–200 doi: 10.1017/S0022112007009548