Micron sized particle separation in the Paul trap

D.S. Lapitsky

Joint Institute for High Temperatures of the Russian Academy of Sciences,

Izhorskaya 13, bld. 2, Moscow, 125412, Russia, dmitrucho@yandex.ru

Abstract

Paper presents the results of theoretical and experimental study of spatial particle separation in an alternating electric field of a quadrupole type in the linear Paul trap. Charged particles of different sizes can be captured inside the trap at atmospheric pressure in air. Simulation of charged particle dynamics showed that in assumption of spherical particles shape and that particle charge is proportional to particle surface area, captured particles inside the trap oscillate at specific heights/layers that determined by particle mass, charge and trap parameters. This result was experimentally confirmed.

1. Introduction

Monodisperse particles with known physical parameters (size, density, etc.) are used in physics of low-temperature plasma [1–4], in the PIV research methods [5, 6], in nanotechnology [7]. Thus the task of producing powders of monodisperse particles is a very important problem. To get powders with monodisperse particles several methods are used: in [8] monodispese particles are obtained from powders by organizing of required particles in standing surface acoustic waves. In [9] particle separation is provided by dielectrophoresis. Particle separation in cyclone devices is widespread and often used to separate both solid and liquid particles from gases [10, 11] and particles with different masses. In mass spectroscopy ion separation in vacuum is provided by Paul traps [12, 13]. Ion dynamics in mass-spectrometers is described by Matheu equation. In air at atmospheric pressure the range of parameters for particle and ion capturing become wider [14]. In works [15–18] the confinement of microparticles by the alternating electric fields has been obtained in air.

The aim of this work is theoretical and experimental investigations on the spatial separation of charged particles from polydisperse powder trapped in linear Paul trap by alternating electric fields.

2. Mathematical simulation of charged particle dynamics in alternating electric fields of quadrupole type

The sketch of the Paul trap is presented in figure 1 [21]. The trap consists of four cylindrical electrodes with radius R_1 = 1.5 mm and length L_m = 30 cm. The alternating voltages $U_\omega\sin(\omega t)$ and $U_\omega\sin(\omega t + \pi)$ were applied to electrodes 1 and 2 of the trap respectively. In simulation the amplitude of the alternating voltage was U_ω = 5 kV and the frequency $f = 2\pi\omega$ was taken 50 Hz. The gravity force was oppositely directed to the z axis.

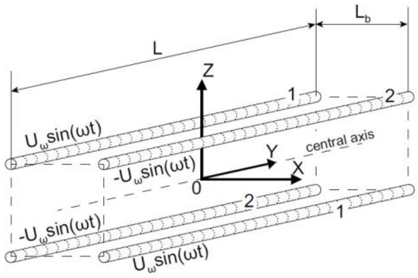

Figure 1. The linear Paul trap.

To simulate the charged particle dynamics in the trap the Brownian dynamics has been used. The microparticle dynamics was described by the following Langevin equation [20]:

$$m_p \frac{d^2 r}{dt^2} = F_t(r) - 6\pi\eta r_p \frac{dr}{dt} + F_b + F_g + F_{\mathrm{int}} \tag{1}$$

where m_p and r_p are particle mass and radius, r is the vector of the particle, η is the dynamic viscosity of air (18.2 μPa·s [21]), $F_t(r)$ is the force of trap electrodes, F_b is responsible for collisions with neutral particles, F_g is the gravity, F_{int} is the interparticle Coulomb force.

Spatial particle separation is presented in figure 2. To study spatial separation the polydisperse powder of 500 particles was injected inside the traps with distances between the axes of the neighboring electrodes L_b = 1.3, 1.6 and 2.8 cm. The powder consisted of particles of 5 types that differed with radius and charge: the radii and charges of the particles of the first type were r_1 = 1 μm and q_1 = 1000 e, for the 2nd type: 2 μm and 4000 e, 3rd type: 3 μm and 9000 e, 4th type: 4 μm and 16000 e, and 5th type: 5 μm and 5000 e. Particles density corresponded to aluminum oxide Al_2O_3 (3990 kg/cm^3).

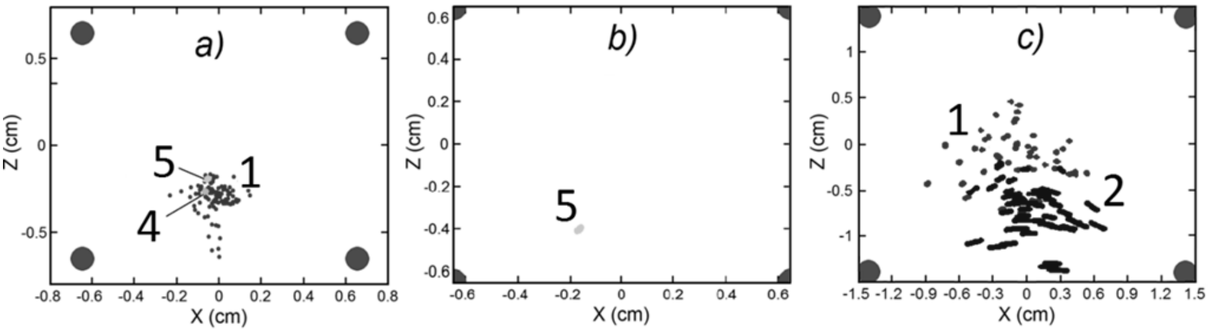

Figure 2. The confinement and spatial separation of particles in traps with a) L_b = 1.3 cm, b) L_b = 1.6 cm and *c*) L_b = 2.8 cm.

Inside the trap with L_b = 1.3 cm the particles of 1st, 4th and 5th types were confined, at L_b = 1.6 cm particles of the 1st and 4th types deposited from the trap, and at L_b = 2.8 cm trap captured only small particles (1st and 2nd types). In figure 2c tracks of particle motion are presented. Stable curves correspond to particle tracks.

3. Experiment on charged particle spatial separation

To study the possibility of spatial particle separation the experimental setup was used the sketch of which is shown in fig 3a. The experimental setup consisted of two separate modules: the corona discharge module 1 for particles charging (the same as in [17]) and the trap module 2 with expanding interelectrode distances: while the horizontal interelectrode distance was constant 1.6 cm, vertical distance increases from 1.6 to 5.5 cm to have the possibility to study particle separation at different interelectrode distances. The alternating voltage was U_ω = 10 kV and the frequency was 50 Hz. The polydisperse powder of particles was injected in corona discharge module where they get charges. Distribution on sizes of particles that fell from corona discharge module to the trap was measured by their deposition on the glass that was putted under the corona module instead of trap. Particle sizes were measured by the microscope. The distribution is presented in figure 4a.

After that glass was changed with the trap to capture charged particles. In figure 3b particle spatial separation is shown. In figure 3b there are two layers: layer of big particles is in the bottom, layer of small particles is on the top and free space between layers. Owing to the free space it was possible to collect particles from two layers separately by two glasses. The particles distributions on sized for top and bottom layers are presented in figure 4b. In figure 4b the distributions are shifted relative to each other according to particle sizes – while for small particles from top layer the distribution function reaches maximum at r_p = 2 μm with average size 5.7 μm, the maximum of distribution function for big particles is at r_p = 11 μm with average size 13 μm.

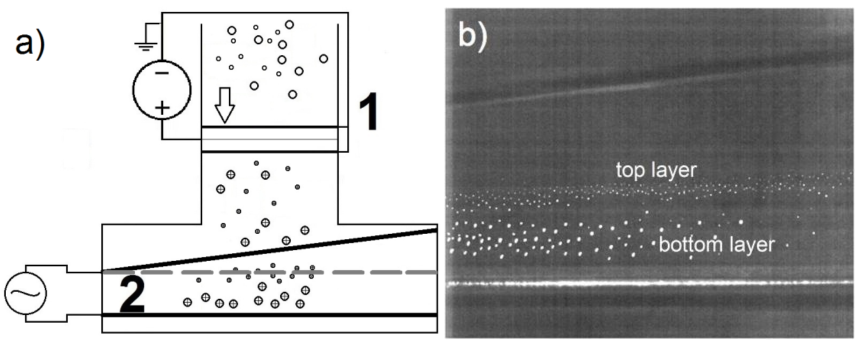

Figure 3. a) the sketch of the experimental setup, b) particle separation in the trap.

3. Conclusion

In the article the spatial particle separation in alternating electric fields of quadrupole type was demonstrated. It was shown that varying the parameters of the trap (the distance between electrodes and frequency of alternating voltage) it is possible to spatial separate particles from the polydisperse powder inside the trap.

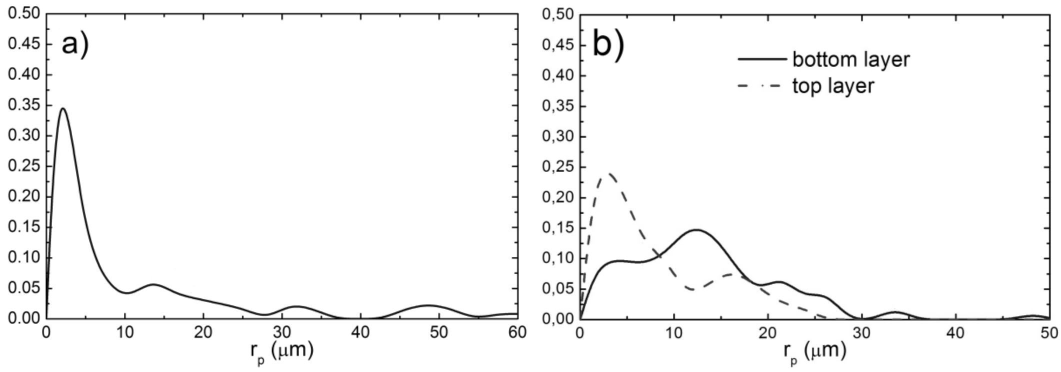

Figure 4. a) particle distribution on sizes from corona discharge unit, b) particles distributions on sizes from different layers.

Acknowledgments

The work was done by the financial support of the Russian Foundation for Basic Research grant No. 16-32-00031 mol-a.

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