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Microparticle dynamics in Coulomb structures in linear electrodynamic traps with different numbers of electrodes

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Abstract. The microparticle dynamics in linear electrodynamic trap with different numbers of electrodes (8, 12 and 16) was theoretically studied. The regions of particle confinement as the dependencies of frequency of alternating voltage on particle charges and number of electrodes were determined. Amplitudes of particle oscillations decreases with the growth of the frequency as well as with the growth of the number of trap electrodes.

1. Introduction

The first demonstration of dust particle confinement by alternating electric field of dynamic electric trap was in 1955 [1]. The analysis of particle dynamics in alternating electric fields was performed in [2, 3], where the motion of the particle was separated into two components: the circular motion of the particle owing to the oscillation of a potential field and slow micromotion.

Nowadays electrodynamic traps are used for creation of self-organized structures with Coulomb interparticle interaction [4]. The effect of charged particle capturing by electrodynamic traps was used for determination of properties of the particles [5, 6]. In papers [7–10] the microparticle parameters needed for particle confinement by a linear quadrupole traps have been determined.

In this paper the studies of charged particles dynamics in linear traps with different numbers of electrodes (8, 12 and 16) were carried out.

2. Model of particles behavior

To simulate the charged microparticle dynamics in the trap and to find the regions of microparticle confinement the Brownian dynamics has been used. The microparticle dynamics was described by the following Langevin equation [7]:

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

where m_p and r_p are the microparticle mass and its radius-vector, η is a dynamic viscosity of gas medium, $\eta = 18.2\ \mu\mathrm{Pa\,s}$ [11], $F_t(r)$ is the force of trap electrodes, F_b are stochastic delta-

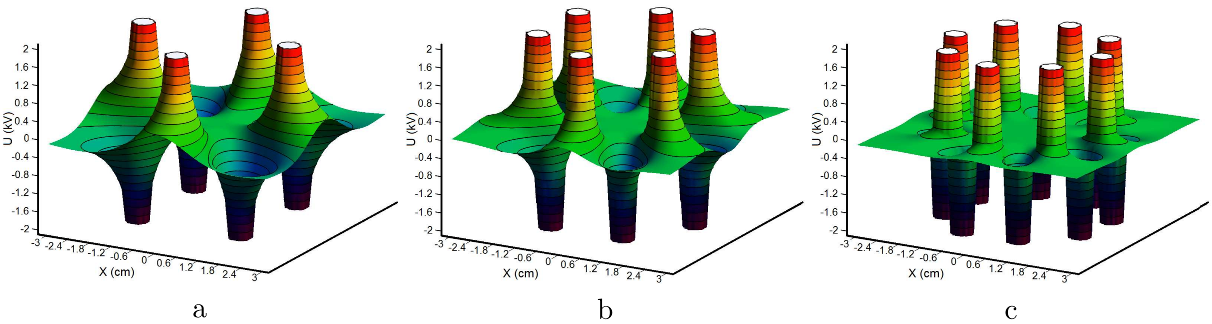

Figure 1. 3D plots for the 8 (a), 12 (b) and 16 (c) electrodes trap.

correlated forces accounting for stochastic collisions with neutral particles, F_g is the gravitational force.

In simulation we used a microparticle with mass density $\rho_p = 3700$ kg/cm^3. For solving the stochastic differential equation (1) we used the numerical method developed in [12].

The Coulomb force acting on the microparticle from each electrode can be approximately presented as the vector sum of forces of point-like charges uniformly distributed along the electrode as in [9].

To simulate the microparticle confinement we use the following parameters of the trap: length of electrodes $L = 6.5$ cm, $R_2 = 25$ cm, $R_1 = 3$ mm, the radius of the trap was $r_t = 4$ cm and magnitude of alternating voltage on the trap electrodes $U_\omega = 2$ kV.

The equipotential surfaces in cross section of linear traps with 8, 12 and 16 electrodes in the center of them are presented in figure 1. The equation of the potential was:

$$U(x,y) = \sum_{j=1}^{N_{\rm el}} \sum_{z_s} \frac{(-1)^j L U_\omega}{2N \ln(R_2/R_1)\sqrt{(x - r_t\cos(2\pi j/N_{\rm el}))^2 + (y - r_t\sin(2\pi j/N_{\rm el}))^2 + {z_s}^2}}, \quad (2)$$

where $N_{\rm el}$ is the number of trap electrodes, z_s is the z coordinate of each point-like charge of trap electrode.

In figure 1 hills correspond to the potential barriers and pits correspond to potential wells that attract microparticles. White holes inside the hills correspond to trap electrodes where there is no electric field. Every half a period of oscillations barriers and wells swapped and each charged particle oscillate between them. This particle oscillations lead to dynamic confinement [13].

Figure 2 presents the confinement regions for the charged microparticle in 8, 12 and 16 electrode trap.

The confinement regions is located between related lines: for 8 electrode trap between solid gray lines, and for 12 electrode trap between dark gray dash lines and for 16 electrode trap between black dash-dot-dot lines. Beyond these regions traps cannot confine particle. At small charge alternating electric field cannot compensate the gravity force and particles flow through the trap and at the right-hand of trapping region the trap field pushes microparticle out of the trap on half-cycle of oscillations.

3. Microparticle dynamics in linear traps

To study influence of the number of electrode trap on the behavior of particles in the trap we have investigated the average amplitude of the particle oscillations in the trap. The dynamics of several microparticles (20 microparticles) in the traps and averaged the amplitudes of particle oscillations was simulated. To do this the time of simulation was chosen long enough to obtain the stable particle oscillations during ten periods.

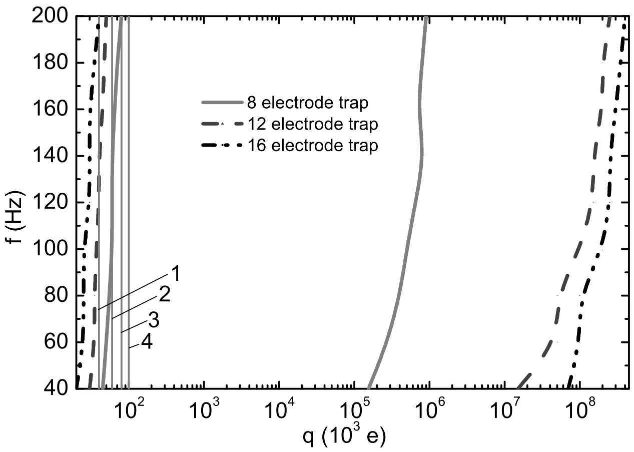

Figure 2. The regions of a single particle confinement as the dependence of the frequency f of alternating voltage on particle charge q_p. The calculation was performed for the following parameters of microparticle: the radius was $r_p = 5$ μm and its charge varied from $q_p = 3 \times 10^4 e$ to $5 \times 10^{11} e$. Vertical lines 1–4 correspond to charges $q_p = 4$, 6, 8, $10 \times 10^4 e$ that were taken to estimate oscillation amplitudes in trap.

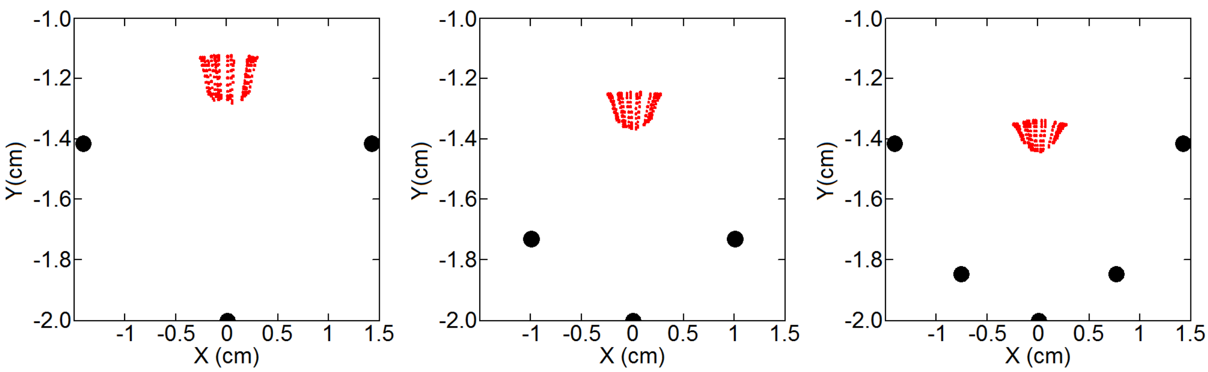

Figure 3. End views of the track of 20 microparticles in 8 electrode trap (a), 12 electrode trap (b) and 16 electrode trap (c). Big black dots in the bottom of the pictures corresponds to traps electrodes (electrodes radii are presented not in scale). The calculation was performed for the following parameters: microparticles radius was $r_p = 5$ μm and charge $q_p = 8 \times 10^4 e$; $U_\omega = 2$ kV, $f = 60$ Hz.

Particle oscillations in 8, 12 and 16 electrode traps are presented in figure 3. Due to the decrease of the gradient of the electric field in center of the trap (figure 1) with increasing the number of electrodes the characteristic tracks of particles are shifted lower.

The dependence of particle oscillation on the number of electrodes is presented in figure 4. In figure 4a at rather low particle charge the dependency of averaged amplitude on the frequency f exists only for 12 and 16 electrode traps because the region of particle confinement for 12 and 16 electrode traps are wider than for the 8 electrode trap. The dependence of oscillation amplitude on number of trap electrodes is complex and depends on the particle charge and interparticle

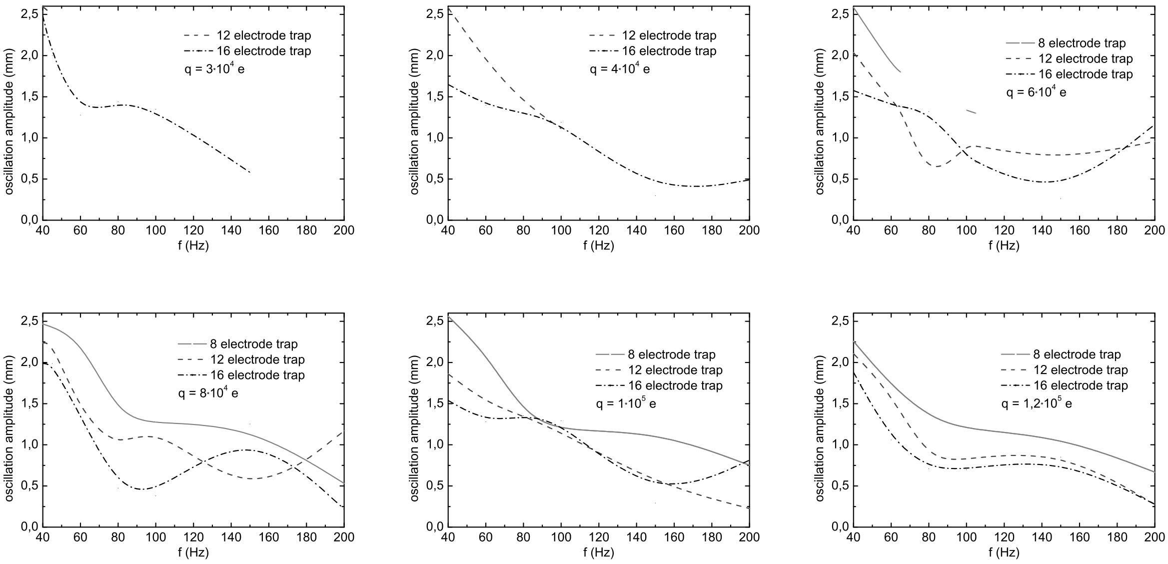

Figure 4. Dependencies of average oscillation amplitude on the number of trap electrodes, the particle charge q_p and frequency f. The calculation was performed for the following parameters: particle radius was $r_p = 5$ μm and charge varied from $q_p = 3 \times 10^4 e$ to $1.2 \times 10^5 e$.

interaction as was mentioned before but the higher the frequency of alternating field the lower oscillation amplitude is. For 8 electrode trap there was found the resonance effect at ~ 60 Hz for particles with charge $q = 8 \times 10^4 e$ which is all particles flew from the trap despite their parameters corresponded to confined area in figure 3.

4. Conclusion

The microparticle dynamics in linear electrodynamic trap with different numbers of electrodes (8, 12 and 16) was theoretically studied. The regions of particle confinement as the dependencies of frequency for alternating voltage on particle charges and number of electrodes were determined. Amplitudes of particle oscillations decrease with the growth of the frequency as well as with the growth of the number of trap electrodes.

Acknowledgments

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