Simulation of bicomponent dusty plasma cluster behavior under electric pulsed loading

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Investigation of the effect of electric field on dusty-plasma crystal behavior is of great theoretical and practical importance[1]. Theoretically important here is the analysis and computer simulation of the mechanisms responsible for the basic properties and behavior of dusty-plasma systems subjected to external action of different types and regimes. Of significance is the implementation of dusty-plasma systems, which calls for extensive studies of the same.

Of special interest is that the charge of dust particles in such systems can change [2]. Dust particles have masses exceeding those of electrons and ions; therefore, the characteristic times for dust particle subsystems are significantly higher relative to electron and ion subsystems. Even a short-time (nanosecond) electrical pulse can affect significantly complex plasma streams, causing thereby a change of plasma properties [3].

Formalism

Using molecular dynamics method, the response of binary dusty-plasma particle systems to the action of electric pulses was investigated. The investigation was performed for two binary systems which contained two sorts of dusty-plasma particles each; the particle radii were 2.3 and 2.5 μm and 2.3 and 3.0 μm, respectively (see the Table).

Table 1: Parameters of dust particles (r - radius of a particle, Q - charge of a particle)

r, μm	Q, e
2.3	1955
2.5	2072
3.0	2353

The theoretical estimation of the dust particle charge as the particle size function was carried out within an analytical approach [4, 5], which is a generalization of the known charge theory in the orbit motion limited (OML) approximation in case if ion scattering on neutral atoms is taken into account. The interaction between particles is determined by the Debye-Hückel potential

$$\phi = \frac{Q}{4\pi\varepsilon_0 r} e^{\left(-\frac{r}{\lambda_d}\right)} \tag{1}$$

where λ_d – plasma screening length (Debye radius) and Q – particle charge. The force acting from the trap side holds the particles together. This is of electrical nature and is given as

$$F = \alpha_z Q z + \alpha_\rho Q \rho \tag{2}$$

where $\rho = (x^2 + y^2)^{1/2}$. The coefficients α_z and α_ρ determine the confining field force in the vertical and horizontal directions, respectively.

To describe the action of nanosecond electric pulse on the dusty-plasma crystal with a resultant change in the particle charge, a phenomenological scheme was proposed. A linear 1.3-fold increase in the particle charge occurred within 0.05 ms under the action of nanosecond electric pulse; then the particle charge decreased exponentially within 0.15 ms. We operate on the assumption that the above scheme of particle charge variation corresponds, in a qualitative sense, to the experimental dependence of time evolution of voltage on an RF electrode due to the action of nanosecond electric pulse [3].

Results of Simulation

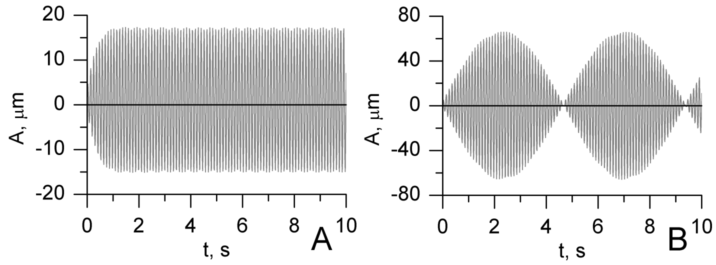

Figure 1: Time dependence of the position of the center of masses in the vertical direction obtained for the dusty-plasma crystal (A) under the action of electric pulses with frequency 8.9 Hz: with regard to friction (A); without regard to friction (B).

The calculations performed show that the amplitude and behavior of oscillation of the dusty-plasma crystal essentially depend on both the electric pulse frequency and the coefficient of friction force acting on dusty-plasma particles from without. In case no account is taken of the friction force, the oscillations in the vicinity of resonance frequency would turn to beats; otherwise the particle oscillations reach a maximum which is determined by the electric pulse frequency and by the friction force of the environment (Fig. 1).

The gain-frequency characteristics are presented for single-component systems in Fig. 2. The oscillation frequency was determined by the displacement of the center of gravity of the simulated system. As is seen from Fig. 2, the resonant frequency value of a single-component dusty-plasma system depends on particle size.

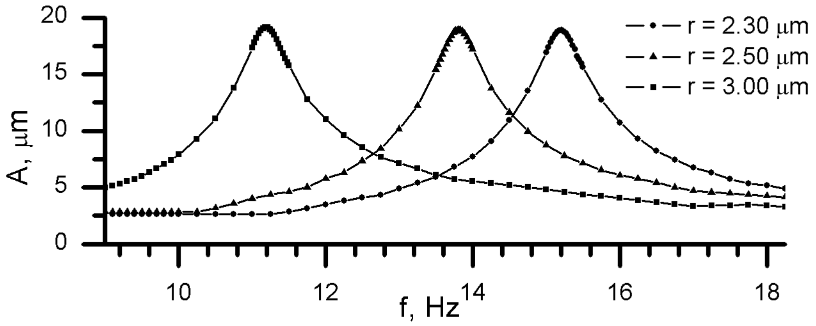

Figure 2: Dependence of oscillation amplitude on electric pulses frequency observed for single-component systems

The binary system behavior under electric pulse stressing was simulated. It is found that the oscillation of the center of gravity is characterized by two resonance peaks (Figs. 3 and 4). The positions and magnitude of the resonances on the frequency response characteristics (see gray curves marked by triangles) correspond with the respective characteristics obtained for the single-component systems. Matching of the curves from Figs. 3 and 4 suggests that the greater the difference in particle size, the greater the peak separation and the difference in the peak height. One would expect that the FR curve behavior of a binary dusty-plasma system might differ significantly in case a difference in particle size is much less that in the case in question. This might be attributed to the fact that particles of different sizes, which are in the ground state of dusty-plasma cluster, would be The FR curve would illustrate this scenario.

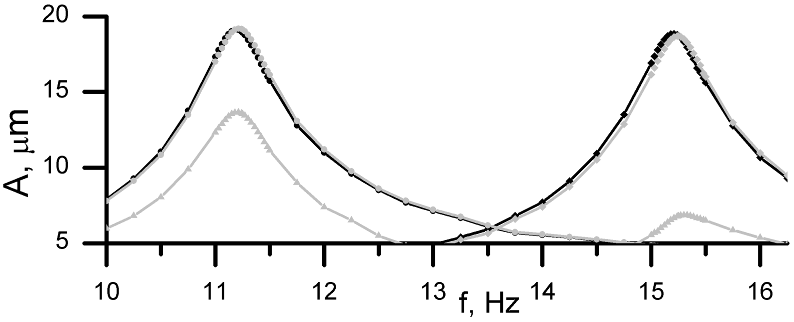

Figure 3: Frequency response (FR) of the binary system marked in gray and black are the curves of binary and single-component systems, respectively; spheres and rhombs denote, respectively, the FR of systems of particles having radius 3.0 μm and 2.3 μm

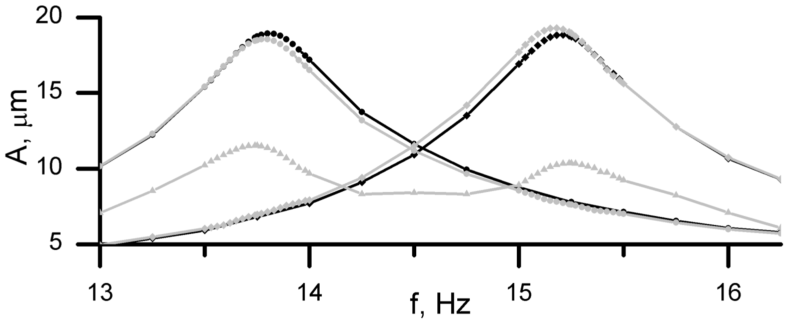

Figure 4: Frequency response (FR) of the binary dusty-plasma system marked in gray and black are the curves of binary and single-component systems, respectively; spheres and rhombs denote, respectively, the FR of systems of particles having radius 2.5 μm and 2.3 μm

Conclusion

It is shown that in the case of binary dusty-plasma cluster under the action of electric pulses, the frequency response of oscillation of the center of masses is conveniently described by the superposition of the oscillations of single-component subsystems with the provision that the particle sizes of the latter differ significantly. Single-component subsystems containing particles having very close parameters would converge, which would enhance the interaction between these subsystems.

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References

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