Control of trajectories and confinement of charged microparticles in a quadrupole trap with rectangular voltage

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Experimental studies and numerical simulations of the motion control and confinement of charged microparticles in a linear quadrupole trap in air at atmospheric pressure have been carried out. The influence of pulse-periodic bipolar rectangular voltage with variable parameters on particle dynamics has been investigated. The experimental setup included a system of cylindrical electrodes with diameter of 4 mm and working length of 10 cm, arranged in a square configuration. Dielectric Al_2O_3 microparticles (10-80 μm) were used. A high-voltage pulse generator allowed independent adjustment of amplitude (3-5 kV), frequency (50-250 Hz) and duty cycle K_p (30-70%) of rectangular voltage. Numerical modeling based on the Langevin equation accounted for electric field forces, gravity, viscous friction and stochastic effects. Maps of stable confinement regions and particle trajectories depending on voltage parameters were constructed. It is shown that variation of frequency and duty cycle K_p enables effective control of the position and width of confinement regions. In symmetric mode ($K_p = 50\%$), horizontal trajectories are observed, while deviation from symmetry leads to stable diagonal trajectories. The dependence of diagonal trajectory orientation on particle charge sign has been established, enabling charge state diagnostics. Confinement regions for rectangular voltage are shifted toward lower charge-to-mass ratio values compared to sinusoidal excitation. Significant expansion of the confinement region for small particles (5 μm) compared to larger ones (50 μm) has been discovered. The use

of rectangular voltage provides enhanced capabilities for microparticle control in quadrupole traps for applications in aerosol analysis, environmental monitoring and functional coating deposition.