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# Electrostatic Particle Acceleration via LINAC: Enabling Next-Generation Solid-State Material Deposition

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Cold spray has emerged as a promising technique for surface metallization and coating, and has been explored for near-net-shape manufacturing applications. The conventional cold spray process faces limitations, including rough surfaces, limited feature resolution, and high energy consumption due to accelerating particles to supersonic velocities using heated gas. To address these challenges, this study proposes a particle acceleration method using an electric-field-based linear accelerator (LINAC) system.

In the proposed approach, charged particles are accelerated through a series of aligned electrodes to form a LINAC configuration. Particles released from a charging source undergo sequential acceleration stages, during which the electric potential energy is converted into kinetic energy. As the particles traverse the drift tube electrodes, the applied voltage at each stage is dynamically switched to ensure continuous acceleration of the particles across the stages. A key challenge in this system is determining the optimal switching time of the electrode potentials to maximize the energy transfer and particle velocity.

To assess the feasibility of this concept, a simulation framework was created to examine how variations in the particle mass, charge, and velocity affect the acceleration efficiency. The findings reveal that an increase in the variability of the particle properties significantly diminishes the effective acceleration of the particle beam. A key observation from this study is that maintaining a constant charge-to-mass ratio alleviates the negative impact of parameter variability, resulting in acceleration profiles that closely resemble ideal scenarios. This insight allows the use of simplified fixed-switching schemes, thereby reducing the system complexity and cost.

In addition to particle acceleration, this study investigates particle–substrate interactions in the proposed electrostatic framework. Unlike conventional cold spray, where particles are uniformly heated by gas flow, the proposed method introduces electrostatic effects owing to the particle charge. As charged particles approach the substrate, image charge formation induces an additional electric field, resulting in further acceleration. At sufficiently high field strengths, field emission occurs, leading to localized thermal effects at the particle–substrate interfaces. This localized heating enhances particle deformation upon impact, which is critical for solid state bonding.

By utilizing experimentally derived charge-to-mass ratios, the temperature increase due to field emission was estimated and integrated into thermomechanical single-particle impact finite element simulations. The findings revealed that the particle temperatures reached approximately 500 K before impact. Comparative simulations demonstrated higher equivalent plastic strain (PEEQ) values than the impacts at room temperature, indicating enhanced deposition efficiency and bonding quality in the proposed system. Overall, this study illustrates the feasibility of an electrostatically driven particle acceleration and deposition process using a LINAC architecture, presenting a potential pathway toward energy-efficient, high-resolution additive manufacturing.

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