

Particle Simulation of Xerographic Line Images

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Abstract

We use three dimensional particle simulations to explain how latent images of lines form in xerographic development systems. Our computational model uses the particle-in-cell technique to track toner particles in time and space under the influence of the numerous forces of xerographic development. Using physically realistic models of toner adhesion, cohesion, air drag, and friction; detailed particle trajectories can be calculated and monitored in self-consistent electric fields. Examples of thin isolated lines, both parallel and perpendicular to the process direction, are analyzed for variations in mass and charge density. Details of the development process are shown to affect the image quality of individual and grouped lines (*i.e.*, ladder charts). Excellent agreement has been observed between simulated development subsystems and experimental data.

Introduction

The use of physics-based design simulators is widespread in many industries such as aerospace, automotive, biotechnology, construction, and electronics. We have produced a similar capability for xerographic print-engine design based on moving individual toner particles under realistic operating conditions. The *Pic3D* code uses the particle-in-cell (PIC) technique[4] to integrate the equations of motion for large ensembles of toner particles within a three-dimensional finite-element mesh. Forces are computed and applied at each time-step on each particle, and include the effects of externally imposed electric fields, space-charge, particle collisions, particle-to-particle cohesion, particle-to-surface adhesion, viscous drag, and surface friction. *Pic3D* is implemented in the C++ object-oriented programming language. As a result, geometry and particle models are easily assembled into *virtual test fixtures* that can be exercised and operated with much the same work practice as a hardware fixture in the laboratory.

Powder-Cloud Development

Figure 1 illustrates a two-dimensional cross-section of a simple development housing which uses a form of powder-cloud development. The housing is shown in the schematic of figure 1 as a capacitor with a moving donor surface along the bottom, and a moving receiver surface along the top. The receiver is generally a photoconductive belt or drum that holds a latent image composed of a differential charge pattern that was composed with a laser or ionographic print head. The donor roll or belt is loaded with a layer of charged toner particles and can move either with or against the motion of the receiver. Typical relative velocities are on the order of many centimeters per second. In jumping development, a larger AC is applied over a smaller DC bias potential across the gap. Toner is dislodged from the donor by the AC fields, transported across the gap by the bias field, and deposited on the receiver. Ideally, the latent image receives toner. The exact geometry of the fixture, along with the frequency and magnitude of the applied electric fields, determines how accurately features of the latent image are resolved. There are many variations of powder-cloud development that we can simulate with the *Pic3D* code.

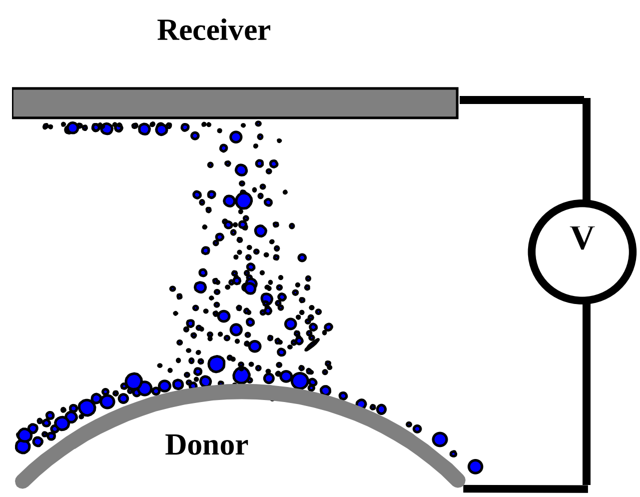

Figure 1. Powder cloud development nip

Development of Isolated Lines

Consider the case of a single thin isolated line that is perpendicular to the process direction. Figure 2 shows an image from a virtual fixture of a train of toner particles being emitted from the powder cloud above the donor. Toner is subsequently deposited on the receiver to form a line as the latent image traverses the development nip.

In Figure 3, we show simulation images of the well-known narrowing of fine lines obtained by varying the background charge on the receiver, i.e. the “cleaning potential". Figure 4 shows three images of a line as it develops in time. This illustrates that thin lines grow from the center outward, and do not just become uniformly denser with time spent in the nip.

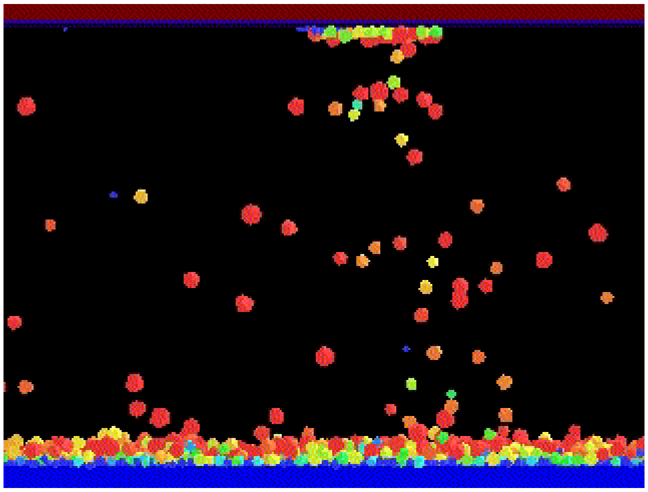

Figure 2. Line development

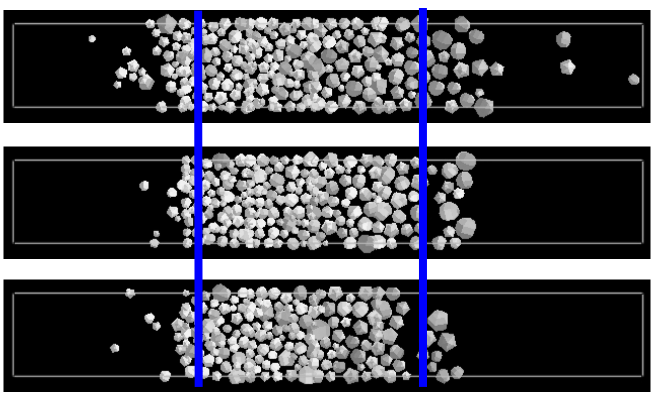

Figure 3. Line narrowing due to background potential

Figure 4. Time sequence of line development

In Figure 5, we see an expanded view of a fully developed line. Several details of the development process are evident. Note that the size of toner particles changes from the lead to trailing edge of the line. Although it may not be evident in a back-and-white picture, we can use colors to illustrate how the particles' tribo (*i.e.*, charge-to-mass ratio) decreases from leading to trailing edge. In the simulations, we see how small, highly charged particles respond to the local electric fields of the latent line image more quickly than more massive particles with little charge. In fact, these large slow particles tend to contribute to excessive line-edge noise on the trailing edge of the image, and show up as background noise in an unoptimized system.

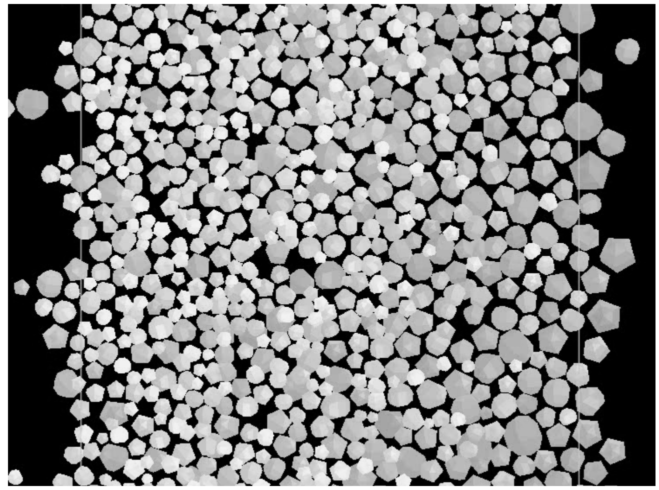

Figure 5. Fully developed line image (lead edge is on left)

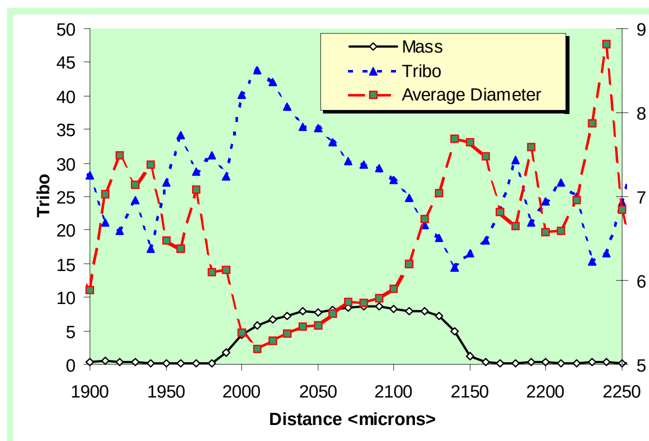

Figure 6. Mass and tribo across a narrow line

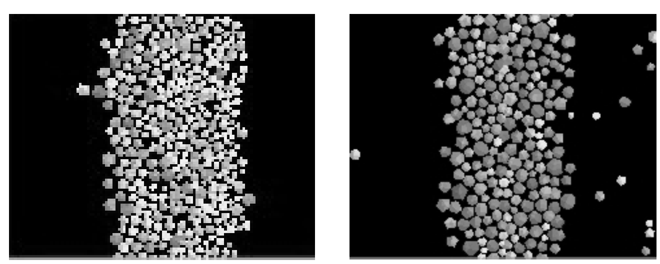

Figure 7. Two types of line development

Figure 6 plots local developed mass density and tribo across the width of the line, further illustrating these points. It is interesting to note (see figure 7) that this lead-to trail edge asymmetry is present in some powder cloud systems, but not in others.

Development of Ladder-Charts

The development of a ladder chart (*i.e.*, an array of closely spaced lines) shows how simulation can be used to optimize design. A product engineering team approached us with a problem: the leading edge of their ladder chart appeared weak or eroded. The ladder chart image produced the same effect in our virtual fixture. (Figure 8). A detailed analysis of the simulation showed that the problem was the fringe electric fields at the lead edge of the ladder chart image which were sweeping toner particles out of the way as it ran through the nip.

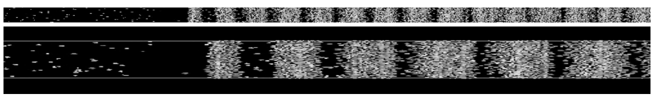

Figure 8. Ladder charts with lead edge erosion

Conclusion

We have shown how particle simulations can be used to predict and analyze macroscopic properties of xerographic line images. The physics of line development has been accurately represented in software by the underlying force models.

References

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Biography

John G. Shaw received his B.S. degree in Physics from the University of Manitoba in 1979, and a Ph.D. in Applied Physics and Engineering in 1983. Since 1984 he has worked for Xerox Corporation at the *Palo Alto Research Center*, *The Design Research Institute* at Cornell University, and the *Wilson Center for Research and Technology* in Webster, NY. His work has primarily focused on simulating complex physical processes using modern computational methods.

Ted Retzlaff received the B.S. degree in Mathematics from Case Western Reserve University in 1967 and a Ph.D. in Mathematics from Cornell University in 1976. For the past ten years, he has worked at the Xerox Corporation's *Wilson Center for Research and Technology* in Webster, NY. Prior to joining Xerox, he taught at the State University of New York at Purchase, worked at M.I.T. Lincoln Laboratory, at Agfa-Compugraphic, and several start-up companies. He has focused on design and development of applications systems for design automation.