

Tools For Simulation of Toner Particle Motion in a TonerJet[®] Printer

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Abstract

In the TonerJet system toner particles move from a toner feeding roller through an array of holes (apertures) in a paper wide flexible printed circuit board to the print media. An electrical field between the toner feeding roller and the back electrode moves the charged particles. A number of electrodes in the circuit board modulate the electrical field, which makes the charged toner particles to either pass through the aperture or to stay on the feeding roller. A pair of deflection electrodes around each aperture makes it possible to deflect the toner particles from one aperture to three different dot positions.

The movement of the charged toner particles has been simulated using two different simulation tools. In the first tool the electrical field is calculated with the software package ANSYS and the particle motion is calculated with the software package ADAMS. In the second tool both the electrical field and the particle motion are calculated in MATLAB.

One aperture is simulated in either in 2D or 3D. The simulated particles are affected by electrical field forces, coulomb forces, mirror forces, collision forces, friction forces and air draught forces.

Introduction

With small dimensions and high frequencies in the process it can be difficult to understand what is really happening in the real printer. Through these simulations it is possible to study the process and how it changes when parameters are changed. This gives a very good understanding of how the process is working.

The first work on a 2D TonerJet model was made in 1994. Some years later ANSYS, for electrical field calculations, and ADAMS, for particle motion simulations, were being used. Less than one year ago a 3D model (also in ANSYS and ADAMS) was finished. As a complement a simple 2D MATLAB simulation tool has been developed. This paper will describe the difference between the models and explain the reasons for having models.

Technology Basics

Toner Transport

Toner particles, in the form of charged polymer spheres, with a diameter of about $10\mu\text{m}$, are applied as a thin layer on the feeding metal roller by a supply roller. The supply roller charges the surface of the monocomponent, nonmagnetic, polymer particle electrostatically. Mirror and adhesion forces hold the charged particles to the roller surface.

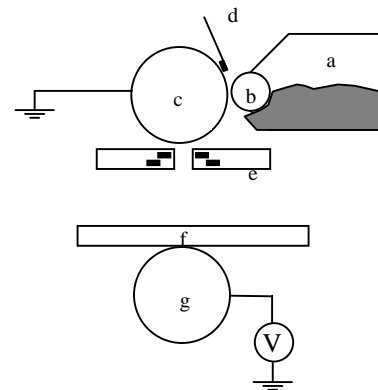


Fig. 1 (a) toner container, (b) supply roller, (c) feeder roller, (d) doctor blade (e) FPC, (f) print media and (g) back electrode.

A flexible printed circuit board (called FPC) is mounted between the feeding roller and the print media. A voltage between the feeding roller and the back electrode below the print media creates an electrical field.

The FPC contains an array of apertures. An electrode that can be controlled individually surrounds each aperture, see Fig. 3. By applying different potentials on the electrodes, the electrical field between the feeding roller and the back electrode can be modulated.

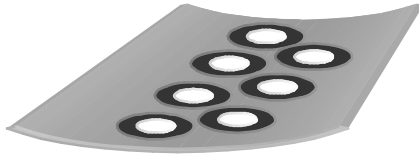


Fig. 2 Flexible printed circuit board with two rows of apertures and ring electrodes. The conductors connecting the electrodes to the IC drivers are not shown.

By modulating the electrical field each aperture can be controlled to be either opened or closed electrically.

Dot Deflection Control

By adding another layer of electrodes on the lower side of the FPC, with two electrodes at each aperture (Fig 3), the toner stream through the apertures can be deflected along the array of apertures. The deflection electrodes are positioned with an angle relative to the array of apertures to compensate for the movement of the print media. By connecting all deflection electrodes on one side of the apertures the whole array deflects the toner in the same direction at the same time. This makes it possible to print e.g. three dots beside each other with the same aperture. A 600 dots per inch resolution printer then needs an array of apertures with a resolution of only 200 apertures per inch.

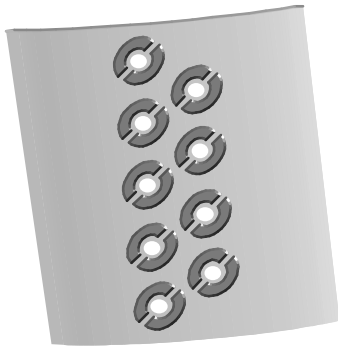


Fig. 3 Lower side of an FPC showing the deflection electrodes. The conductors connecting the electrodes to the IC drivers are not shown.

General Description of the ANSYS/ADAMS Model

In this model the toner movement from the feeding roller to the print media is simulated.

The first model was developed as a two dimensional model, where the particles were allowed to move in only one plane. The electrical field was also calculated in only one plane.

The two dimensional model has now been developed to also handle particle movement in three dimensions, where also the electrical field is calculated in three dimensions. Today a number of up to 200 particles are simulated at the same time.

The ADAMS model consists of the toner feeder roller, the FPC, the print media and the back electrode. None of these moves because their speed is rather low relative to the toner particle stream.

The aperture is about $100\mu\text{m}$ in diameter and the distance between the feeder roller and the print media is typically $400\mu\text{m}$.

Each toner particle is modelled as a point-mass part in ADAMS. The diameter of the particles is normally distributed with an average diameter of about $10\mu\text{m}$, average weight of about 0.1ng and average charge to mass ratio of about $15\mu\text{C/g}$.

The forces attracting the particles are measured in nN.

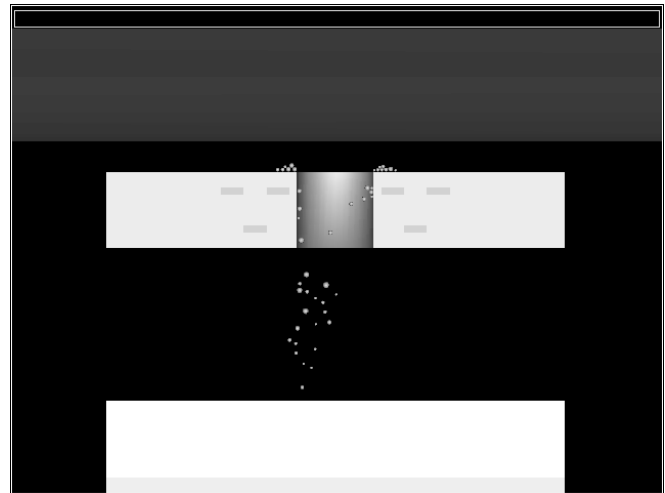


Fig. 4 Example of simulation with the ANSYS/ADAMS tool. A simulation of one print pulse with 45 particles deflected to the left side.

Forces Acting on the Particles in the ANSYS/ADAMS Model

Electrical Field Force

The electrical field components are calculated with the Finite Element Analysis software ANSYS. A C-routine extracts the FEM data from the ANSYS output files and stores the results in a matrix. The matrix with the field data is then linked together with the ADAMS binary code to produce a custom ADAMS/Solver that contains the electrical field data.

For every time step, the electrical field component is fetched from the matrix through a user-written subroutine.

The electrical field force is calculated from the electrical field and the charge of the particle:

$$F = Q * E \quad (1)$$

Coulomb Force Between the Particles

The Coulomb force acts between two charged particles in the model and is calculated by Coulomb's law:

$$F = Q_1 * Q_2 / 4\pi * \epsilon_0 * r^2 \quad (2)$$

To avoid a large number of forces in the model a user-written subroutine calculates the Coulomb force between the current particle and all the other particles once at the beginning of each time step. The Coulomb force component is then stored in a Common Block in a Fortran subroutine. The next time the user-written subroutine is called, it checks if the force has already been calculated for the current time step. If the value has been calculated it is fetched from the Common Block, otherwise the Common Block is recalculated.

Impact Force Between Particles and Fixed Parts

The collision forces between particles and fixed parts are modelled as a spring-damper element with the IMPACT function in ADAMS. When a particle hits a part or another particle, the collision force becomes active when the surfaces of the bodies start to overlap.

All collision detection and impact calculations are handled in a user-written subroutine. A number of 'if' statements checks if the particles are free in the air or if they are colliding. If no contact occurs, then the subroutine directly returns a zero force.

If the particle is colliding, a number of 'if' statements check where the particle is, and calculate the appropriate impact force.

At the beginning of each time step, the collision force is calculated between all particles and parts. The result is stored in a Common Block in Fortran. The next time the user-written subroutine is called, the routine checks if the force already has been calculated for the current time step. If the force has been calculated the results are fetched from the Common Block, otherwise the forces are recalculated and the new result is stored in the Common Block.

Friction Force

The friction force is calculated as the friction coefficient multiplied with the impact force to a static part (developer sleeve, FPC or print media). The friction coefficient change between static and dynamic friction dependent on the particle's velocity relative to the static part. The transition between dynamic and static friction is modelled with a STEP function.

Mirror Force

The mirror force comes from free charges in conductive materials that are attracted to the surface when a particle is close to the surface.

The mirror force depends on the distance from the centre of the particle to surfaces in the model and the charge of the particle:

$$F = Q^2 / (d^2 * 4 * \pi * \epsilon_0) \quad (3)$$

The force is calculated in a user-written subroutine once for each time step.

Air Draught Force

The air draught force is calculated from Stoke's theorem and depends on the velocity of the particle:

$$F = 6 * \pi * \eta * r * v \quad (4)$$

The force is calculated in a user-written subroutine once for each time step.

Description of the Matlab Model

The Matlab model is 2D and simpler than the ANSYS/ADAMS model. The Matlab model consists of the toner feeder roller, at the top of Fig 5, and the print media, bottom Fig 5. The electrical fields and the particle paths are only calculated in one plane only. Between them the electrodes and the toner particles are positioned. It is possible to use 10 electrodes, 10 particles and 10 events in this model.

The electrode voltages are sent to a C-routine, where the electrical fields for the events are calculated. The matrix with the field data is then sent to another C-routine, where the particle paths are calculated. All the data is then sent back to Matlab, where it is plotted as in Fig 6.

The largest differences between the two models are the forces acting on a particle. In the ADAMS model we have implemented all the forces described in the section above. This should be compared with the Matlab model where only electrical field forces and air draught forces are implemented. There are no contact forces so the particles can e.g. go through an electrode. This is not physical but simplifies and speeds up the model.

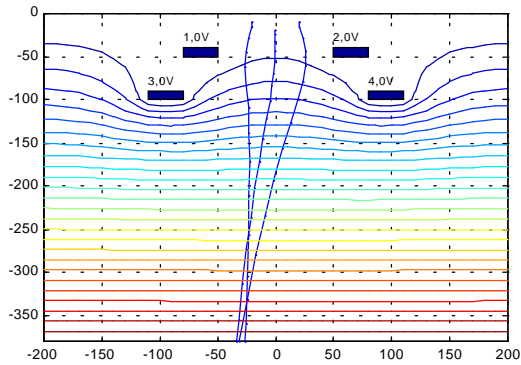


Fig 5. Example of simulation with the Matlab tool, showing three particle paths deflected to the left. Equipotential lines for the current event in the background. The scales are in μm . Electrode 1 and 2 constitute the ring electrode, 3 and 4 are the deflection electrodes.

Why Two Models?

We wanted to create a simulation tool that was easy to use, so that everybody could use it at all times for quick, small tests of new ideas. Although the ANSYS/ADAMS model is very powerful and useful for thorough investigations, we felt that it was not suitable for this purpose. We needed something simpler and faster. The major advantages of our Matlab model are its ease of use and its speed. Its drawback is that it is in some cases too simple, but the startup time for someone familiar with the TonerJet is less than half an hour, which makes the Matlab model an excellent complement to the ANSYS/ADAMS model.

How the Model is Compared With Reality

By using a special printer with only one aperture, a microscope and a high speed camera it is possible to record the sequence of the print pulse on videotape. The video camera takes 40 000 frames per second.

By directly measuring on print samples (e.g. position) it is possible to compare the simulations and the real print process.

With the particle analyser E-spert, it is possible to measure the mass and charge of a toner particle sample.

Conclusions

It is complicated to perform an exact verification of the model due to difficulties in measuring some parameters in the process. The process has a bit of a chaotic behaviour, which also may make it difficult to verify the absolute results from the simulations. Even though this, our two simulation tools are very valuable tools for studying the trends in the process when adjusting the different parameters.

Most of the difficulties in the modelling are connected to the characteristics of the surfaces in the model. Today the surfaces are modelled as plane surfaces with a friction coefficient, but in reality the surfaces are rough compared to the size of the particles.

With small dimensions and high frequencies in the process it can be difficult to understand what is really happening in the real printer. Through these simulations it is possible to study the process and how it changes when parameters are changed. This gives a very good understanding of how the process is working.

To have one simple tool for the first tests and then a more advanced tool and model for more thorough investigations is an effective solution.

Biography

Anders Berg-Palmqvist received his M.Sc. in Engineering Physics from Chalmers University of Technology in Göteborg, Sweden. Mr Berg-Palmqvist joined Array Printers 1997 and is working with the development of the TonerJet print process.

Johannes Åkesson received a M.Sc. in Electrical Engineering from Chalmers University of Technology in 1997. He joined Array Printers AB in 1996, and has been working with development of simulation tools for the TonerJet process.