

Simulation of toner particle movement in a TonerJet printer.

Array Printers AB, 1998
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Abstract

The movement of charged toner particles in an electrical field is simulated. The toner particles move from a feeding roller through an array of holes (apertures) in an A4-paper wide flexible printed circuit board to the print media. A number of electrodes in the circuit board create an electrical field, which accelerates the charged toner particles and makes them move from the toner feeding system to the print media. The simulated particles are affected by electrical field forces, coulomb forces, mirror forces, collision forces, friction forces and air draught forces. The units used in these simulations are nanonewtons, micrometers, milliseconds and nanograms.

Technology basics

Toner transport

Toner particles in the form of charged plastic spheres with a diameter of about $10\mu\text{m}$ are applied in a thin layer on feeding steel roller by a brush. The brush charges the surface of the plastic particle electrostatic. Mirror forces holds the charged particles to the roller surface.

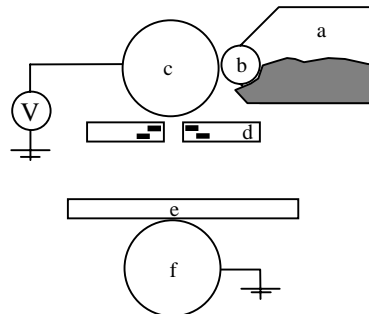


Fig. 1 (a) toner container, (b) brush, (c) feeder roller (d) FPC, (e) print media and (f) back electrode.

A flexible printed circuit board (called FPC) is mounted in the area 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 between the feeding roller and the back electrode.

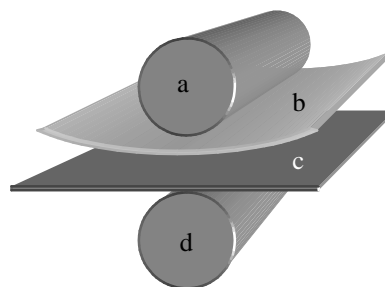


Fig. 2 (a) feeding roller, (b) FPC, (c) print media and (d) back electrode.

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.

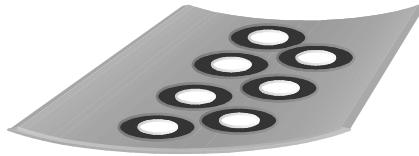


Fig. 3 Flexible printed circuit board with two rows of apertures and ring electrodes.
The conductors connecting the electrodes to the IC drivers are not shown.

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

Dot Deflection Control

By adding another layer of electrodes on the lower side of the FPC, 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 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. E.g. a 600 dots per inch resolution printer then needs an array of apertures with a resolution of only 200 apertures per inch.

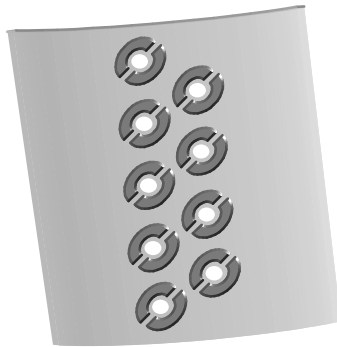


Fig. 4 Lower side of an FPC showing the deflection electrodes.
The conductors connecting the electrodes to the IC drivers are not shown.

General description of the model

In these simulations 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 modelled as the ground part. None of these moves because their speed is rather low relative to the toner particle stream.

The aperture is about 100µm in diameter and the distance between the feeder roller and the print media is about 300-400µm

Each toner particle is modelled as a point-mass part in ADAMS. The particles diameters are normally distributed with an average diameter of about 10 µm and average weight of about 1e-13 kg.

The forces attracting the particles are measured in nN.

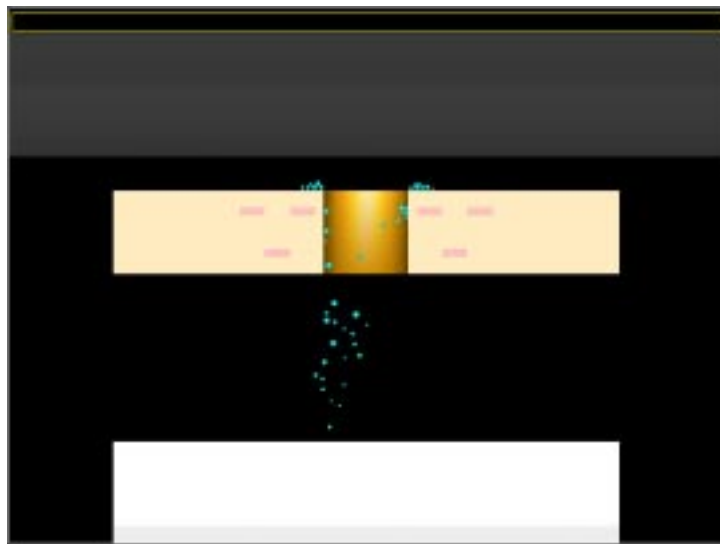


Fig. 5 A simulation of one printpulse with 45 particles deflected to the left side.

Forces acting on the particles

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:

$$F = Q * E$$

Coulomb force between the particles

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

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

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 timestep. 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 timestep. If

the value has been calculated it is fetched from the Common Block and 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 starts 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' statement checks where the particle is and calculates the appropriate impact force.

At the beginning of each timestep the collision force is calculated between all particles and parts and 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 timestep. 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 the ground. The friction coefficient change between static and dynamic friction dependent on the particle's velocity relative to the ground 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 the 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:

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

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

Air draught force

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

$$F = 6 * \pi * \eta * r * v$$

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

How the model is compared with reality

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

By directly measuring on printsamples it is possible to compare the simulations and the real printprocess.

With the particle analyser Espart is possible to measure the mass and charge of a toner particle sample.

Conclusions

It is difficult to perform an exact verification of the model due to difficulties in measuring some parameters in the process. The simulations have a bit a chaotic behaviour which may make it difficult to verify the absolute results from the simulations. Even though these simulations are a very valuable tool for studying the trends in the process when adjusting the different parameters.

The most difficulties in the modelling are the characteristics of the surfaces in the model. The today's surfaces are modelled as plane surfaces with a friction coefficient, but in reality the surfaces are rough compared to the particles size.

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.