Simulation of Toner Mixing and Delivery System

A. Ecer, V. Rubek, K. Arican Technalysis Inc.; Indianapolis, Indiana/USA

Abstract

Detailed analysis of electro-photographic processes requires modeling of individual particles with DEM models. On the other hand, mixing of toners require analysis of billions of particles which is not practical to analyze using DEM models. One can employ continuum models for solution of such problems. The objective of this development is to couple both types of analyses. DEM models are used in regions which require modeling of microscopic properties of material in one region and continuum models are used to model macroscopic behavior of billions of particles at another. These two models are then analyzed in coupled form. Applications of both models have been demonstrated individually [1, 2]. In this paper only the coupling of these two models is presented. The above approach enables solution of problems such as coupling of mixing region in a printer with charging, development, transfer etc.

Another issue presented in this paper is the determination of macroscopic properties of the continuum model which is a difficult problem. These material properties are determined by comparing the results of the DEM model with the continuum model for simple experiments.

The example problem analyzed in this paper is the feeding of a charging blade with a roller, where mixing is occurring simultaneously with a pedal of larger dimensions.

Introduction

Modeling of toner mixing process involves billions of toner particles. It is not practical to model them using DEM due to restrictions in computer resources and time to compute. One can model such problems using continuum models where toner is modeled as a Non-Newtonian material [1]. On the other hand most of the electro-photographic processes such as development or transfer occur at a microscopic level where individual motion of each toner particle has to be calculated [2]. While dimensions involved in such processes are at the micron level, mixing analysis involves dimensions specified by millimeters. One has to couple these two types of processes to ensure feeing from the mixing region is properly modeled. Coupling of both types of processes requires modeling of microscopic properties of material as well as macroscopic behavior of billions of particles in the mixing region.

In this paper, we demonstrate the coupling of DEM and continuum models on a simple example. Mixing is done by a paddle with dimension in the order of centimeters. Transport is achieved by a moving roller surface through an opening under a blade with a size of several microns. FEM and DEM models are separated by an interface across which there is mass and charge transfer between two models/regions. This approach is applicable to mixing problems with several rollers.

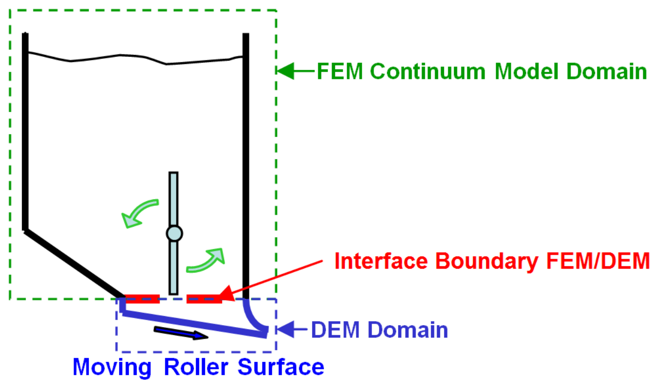

Figure 1. *Geometry to be analyzed: Mixing Region with a Moving Roller Surface*

DEM Model

Physical properties of the toner in small scale such as particle shape, size and surface properties are used for the DEM models. Motion and charging of each particle is calculated individually. Material properties are specified for each toner particle. As an input to the model, shape and size distribution and individual physical property of each component of toner are provided. The forces acting on each particle are analyzed including the interaction with the roller to determine their motion. Charging of each particle and the electrical forces are also calculated [1].

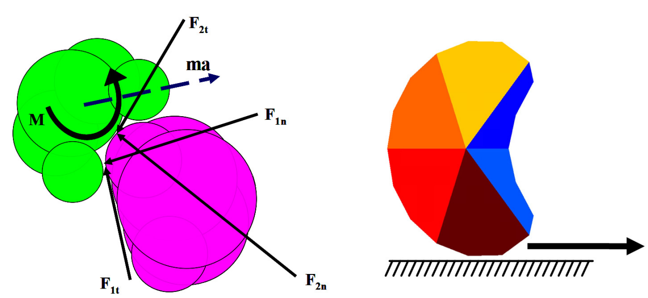

Figure 2. *Models for calculating motion and charging of particles.*

Material properties for particles required for the DEM model can be measured although the shape and size varies from one particle to another. The difficulty of DEM approach relates to the number of particles. As the number of particles grows, computational cost increase and it surpasses the existing capacity of computer resource. Although DEM can be used to simulate many electrophotographic processes, for the mixing and feeding problem presented in this paper, it is not practical to solely rely on DEM approach

Continuum Model

One can use continuum models without being concerned about the size of the problem, large or small. The difficulty with the continuum model is in defining material properties. The assembly of particles is defined as a nonlinear material with properties such as stress-rate of strain relationship, yield stress, etc. These material properties for the continuum model are difficult to measure directly. They can be determined by comparing the results of the DEM model with the continuum model for simple experiments. Microscopic material properties, such as elastic properties, friction, etc., used in the DEM solution can be linked to the macroscopic non-Newtonian properties of the continuum model for the same simple experiment.

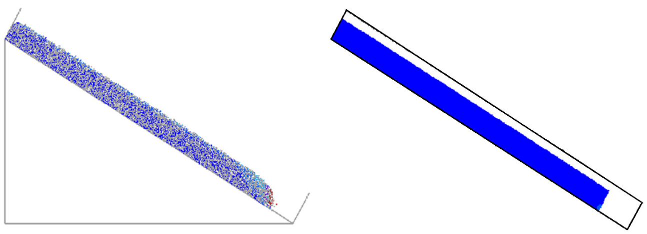

Figure 3. *Simple Experiment: Particle Flow on a Slope- Comparison of DEM and Continuum Models to Determine Material Properties of the Continuum Model*

Coupling of DEM and Continuum Models

In order to solve the described problem, we only consider number of particles less than one million which are located in the immediate neighborhood of the roller while billions of particles are located in the region of interest. We then construct a continuum model for the larger mixing area to analyze the mixing by the continuum model. We then develop a DEM model for covering the feeding area near a blade.

The steps of the analysis are as follows:

- Determine the microscopic physical properties of the toner material. Determine macroscopic physical properties by performing a simple experiment.
- Develop continuum and DEM models for both regions.
- Couple the two models and solve.

The parameters to be coupled are force/velocities and charges. The basic variables in each model are:

- DEM Model: Particle forces, velocities and charges
- Continuum Model: Pressure, velocity and charge distributions.

For the example problem, the continuum and DEM models are defined as shown in the Figure 4.

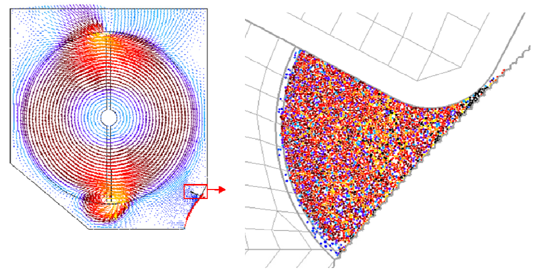

Figure 4*. Continuum a DEM Models*

The coupling between the two models involves distributed variables such as pressure, velocity and charge in the continuum model to be transferred to particle properties and received in return.

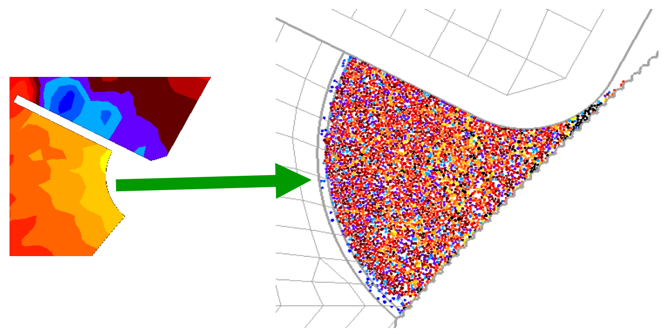

Figure 5. *Transfer of pressure distribution from the continuum model to the forces on individual particles of the DEM model.*

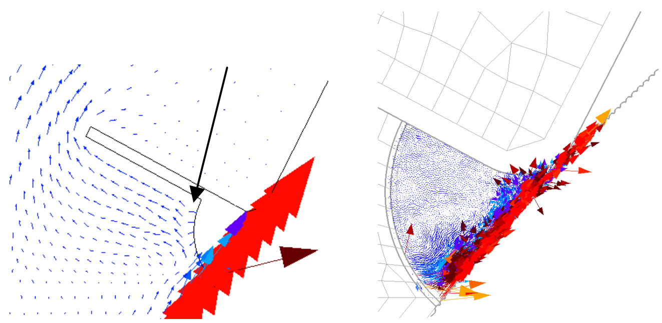

Figure 6. *Transfer of velocity and charge of particles in the DEM model to the velocity and charge distribution of the continuum model.*

The coupling process can simply be described as follows:

- Pressures are calculated from the continuum model and transferred to particle loads, on the interface boundary.
- Velocities are calculated from the DEM model and transferred to the continuum model, Particle velocity is applied as a boundary condition to continuum model nodes on the DEM/FEM boundary.
- Charges are transferred from one model to another following the direction of velocities.

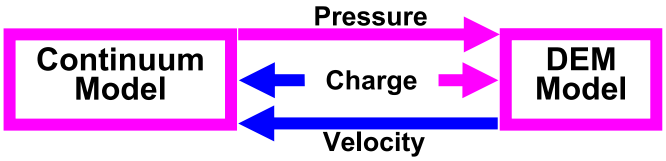

***Figure 7**. Transfer of information between two models during the coupling process*

Although the solutions are marched in time simultaneously, the time steps required for the stability of each solution is different. Generally, the time step required for the DEM analysis is much smaller. Solution of the continuum model and exchange of boundary conditions between models occur after numerous time stepping of the DEM solution.

Test Case

A sample problem was solved where the continuum model included 28000 grid points and the DEM model had only 5000 particles at a given time. The time step size in the continuum model was approximately 1.0e-05 second while the time step size in the DEM model was around 3.35e-09. So, about 3000 time steps in DEM model corresponded to one time step in continuum model.

More detailed results will be presented at the conference.

References

[1] Modeling electrophotographic developer flow with a viscous fluid, Y. Takuma, T. Mitsuya, K. Kataoka, H. Ueki, T. Sugaya, V. Rubek, A. Ecer, The Journal of Imaging Science and technology 47:22.

[2] A, Ecer, V. Rubek and K. Arican. Computer Simulation of Mixing of Toners in Electro-photographic Processes, NIP 26, Loisville, KY, 2010) p. 365-367

Author Biography

Dr. Ecer received his Ph.D. from University of Notre Dame. He is the President of Technalysis and Professor Emeritus of Mechanical Engineering at Indiana University – Purdue University (IUPUI)

Mr. Rubek received his MS in Mechanical Engineering from Purdue School of Engineering and Technology at IUPUI. He is the Director of R&D at Technalysis. He works on the development of DEM and continuum models for printing processes.

Mr. Arican received his MS in Mechanical Engineering and Electrical and Computer Engineering from Purdue School of Engineering and Technology. He is a senior consultant at Technalysis working on printing simulations.