Numerical Simulation of Electrophotography Processes

Hiroyuki Kawamoto

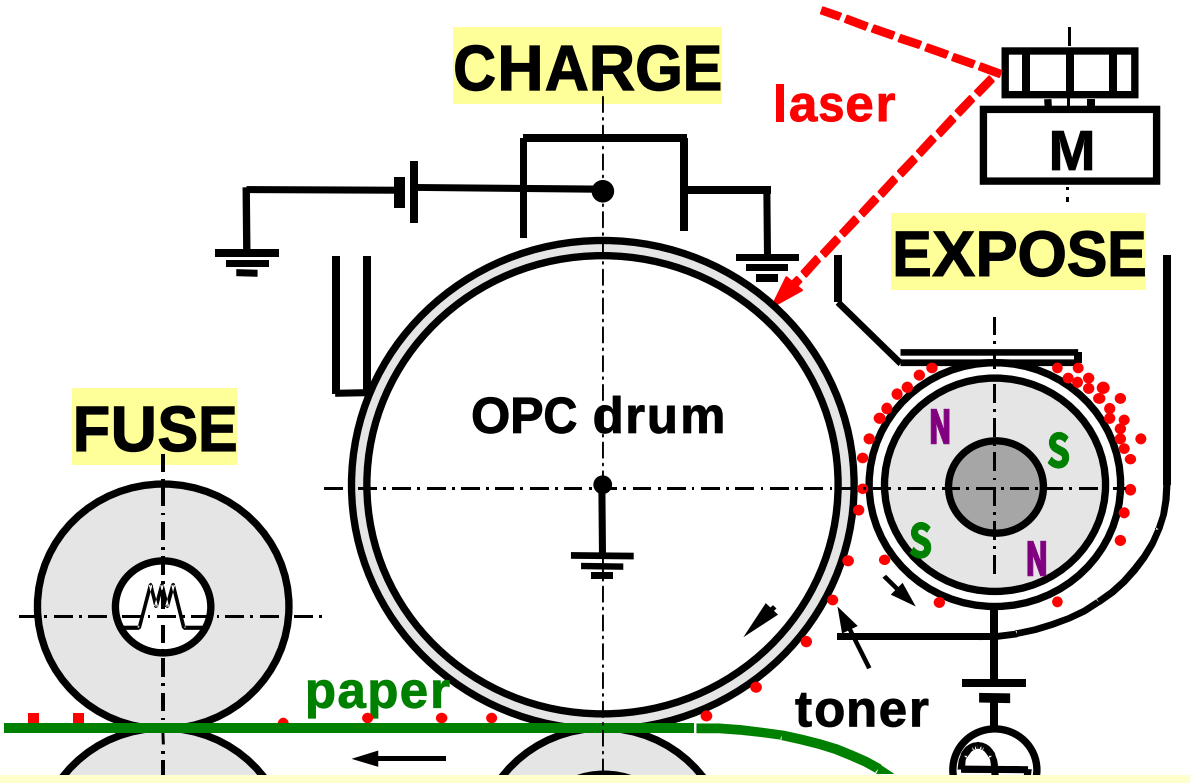
Waseda University, Tokyo

Outline

- **Overview of the recent progress of simulation technology for the development of electrophotography processes**
  - **especially developed in Japan**

- **Promotion of simulation technology and education of young engineers in Japan**

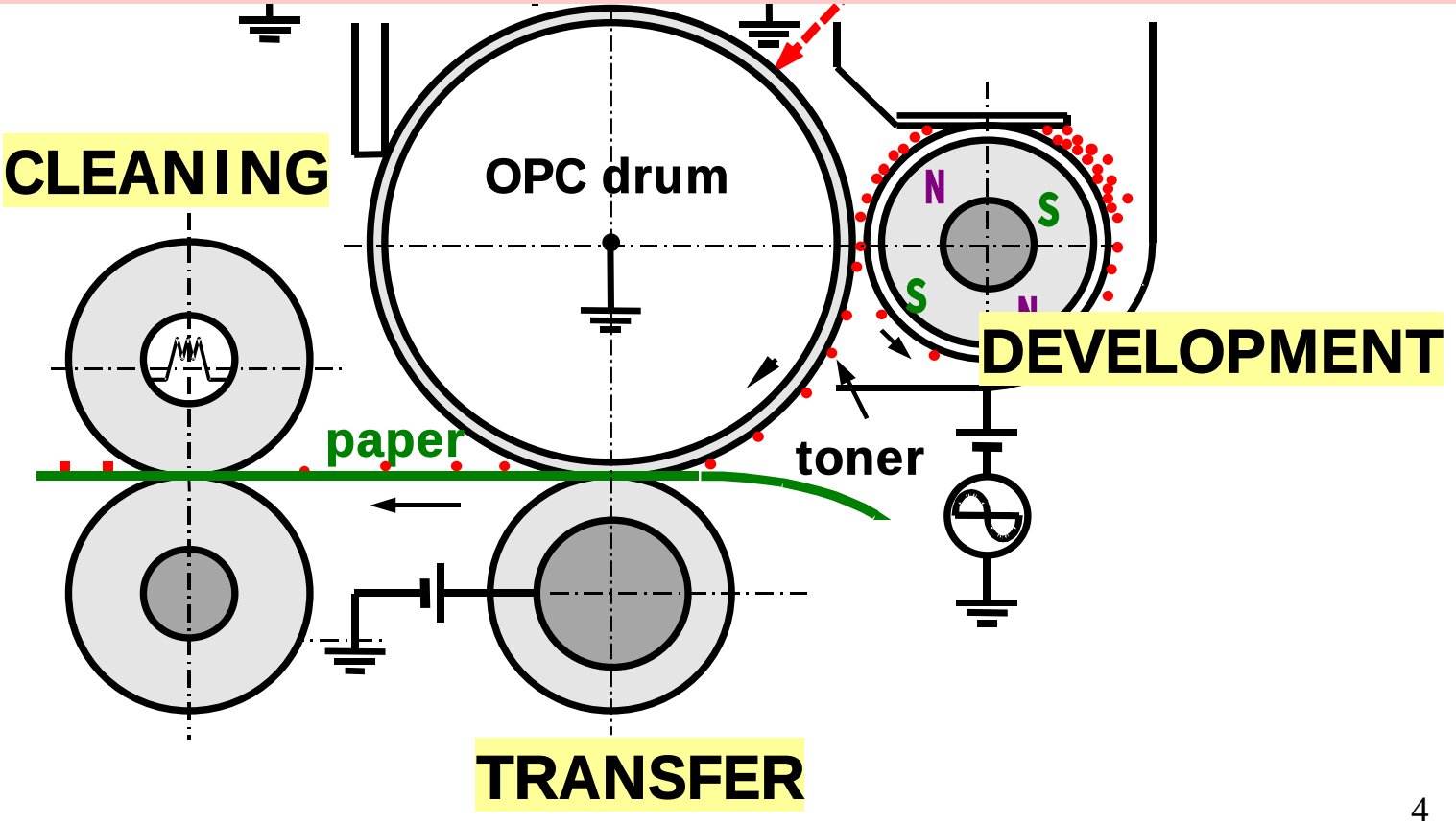
Charging, Exposure and Fusing Systems



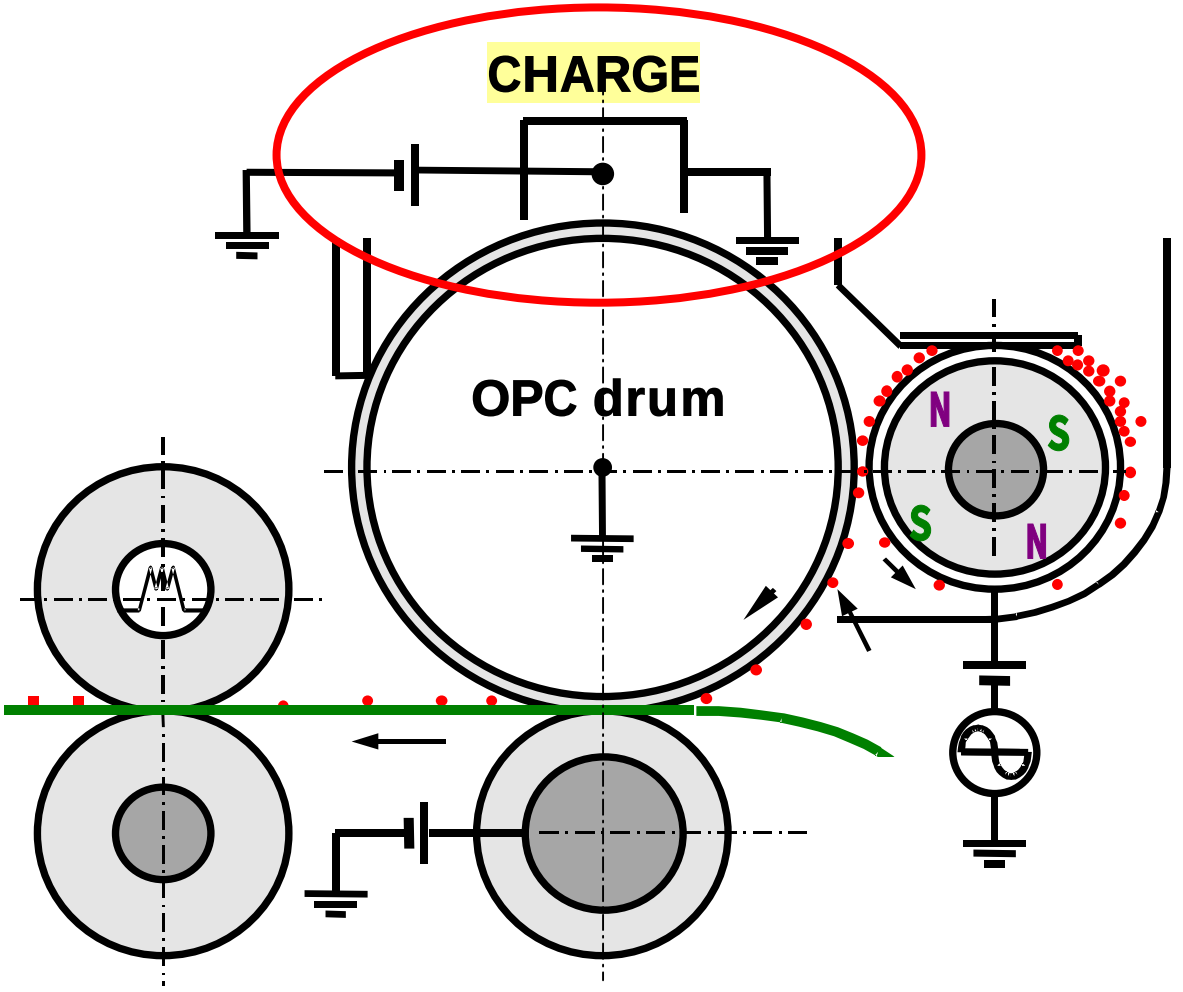
- based on the mechanics of continuous media
- formulated as a set of multi-component, nonstationary, and nonlinear partial differential equations
- numerically solved by the iterative FEM or FDM.

Development, Transfer and Cleaning Systems

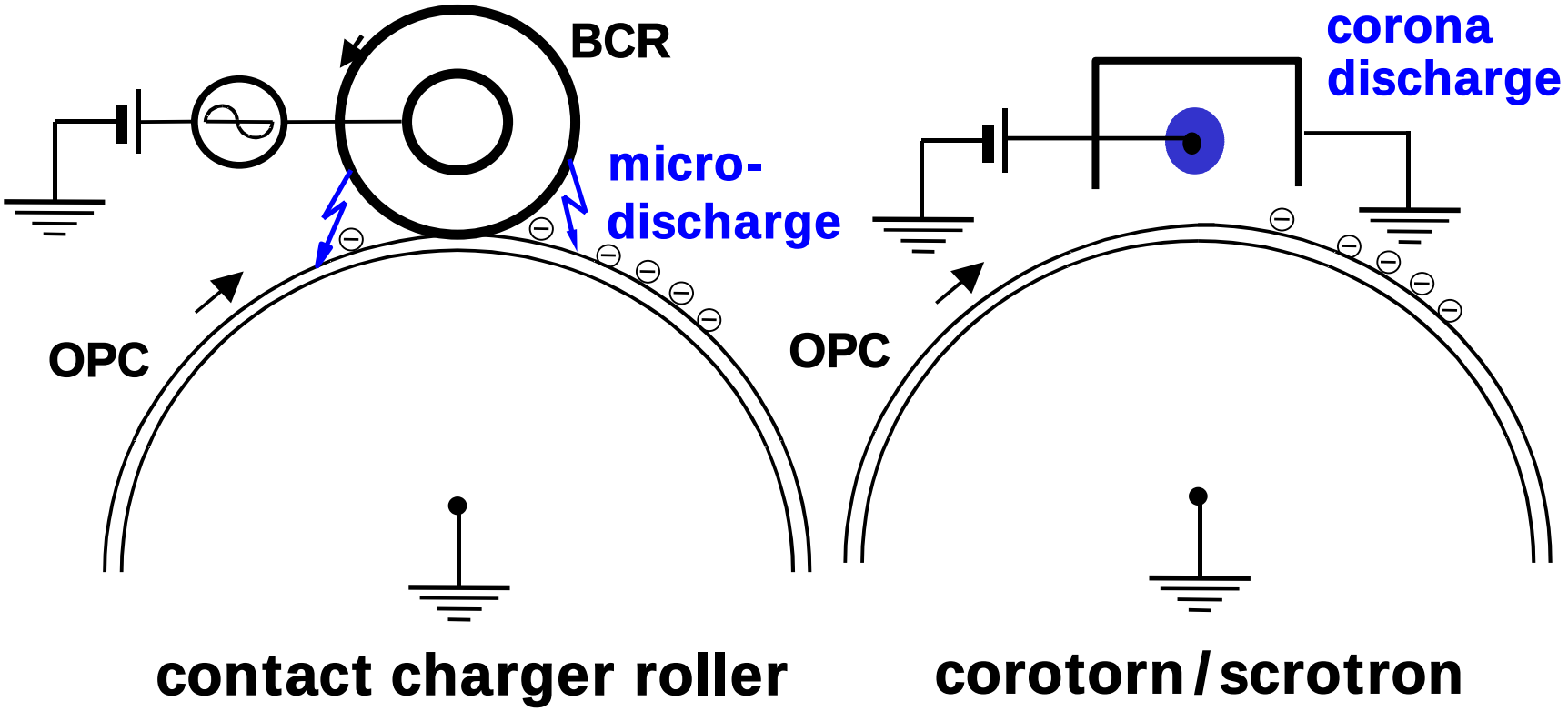
- dynamics of toner and/or carrier particles
- the discrete element method (DEM)
- direct observation with a high-speed microscope camera



1. Charging



Charging Devices



contact charger roller

corotorn / scrotron

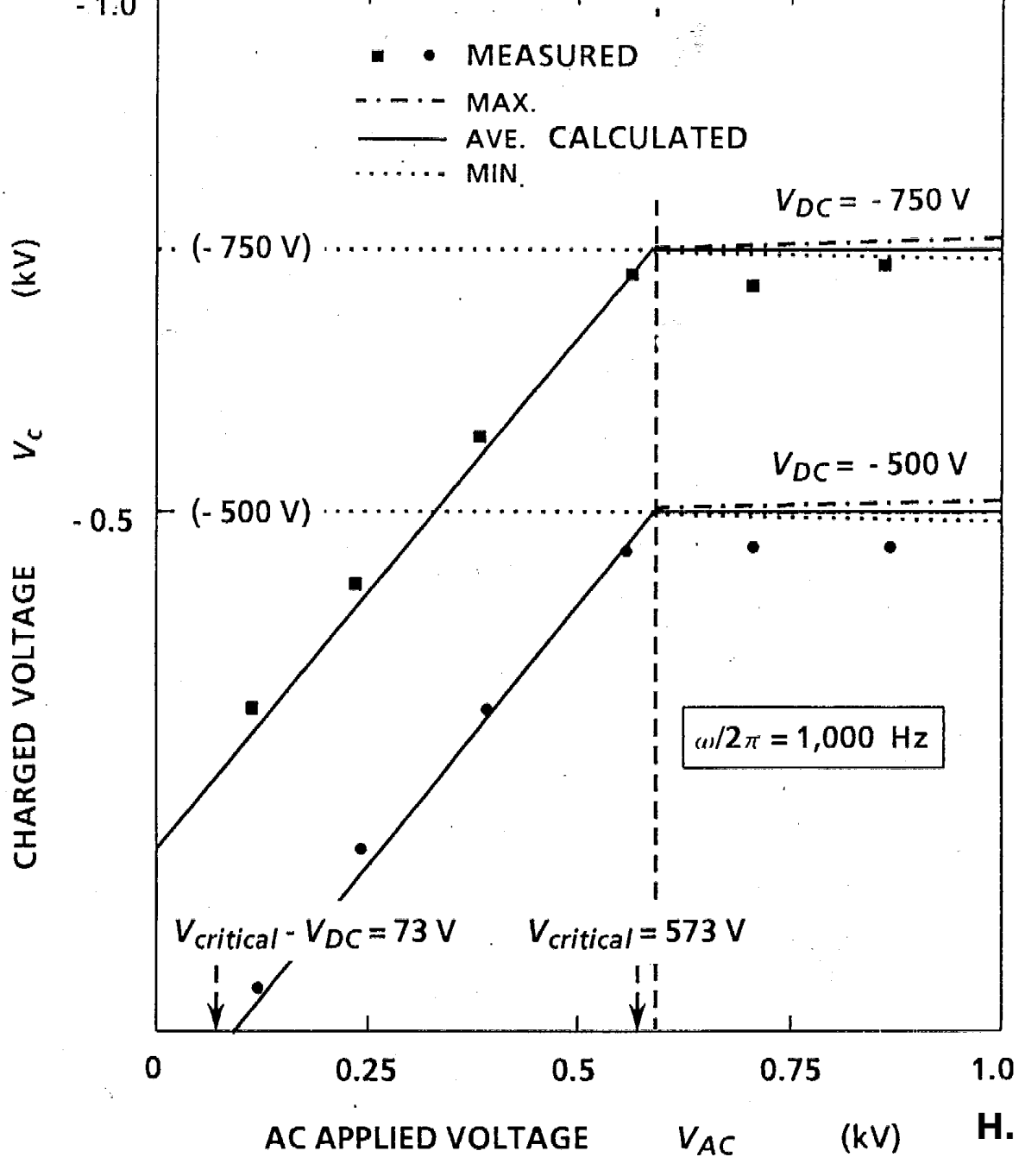
Modeling of Contact Charging
(one-dimensional analytical)

■**charged voltage** $V_c(t) = q(t)\dfrac{d}{\varepsilon_0 \varepsilon_r}$

- **charge density** $q(t+\Delta t) = \dfrac{\varepsilon_0 \varepsilon_r}{d}\left\{V_a(t) - \dfrac{d + z(t)\varepsilon_r}{z(t)\varepsilon_r} V_{th}(t)\right\}$

Micro discharge takes place
when (gap voltage)＞(Paschen V_{th})

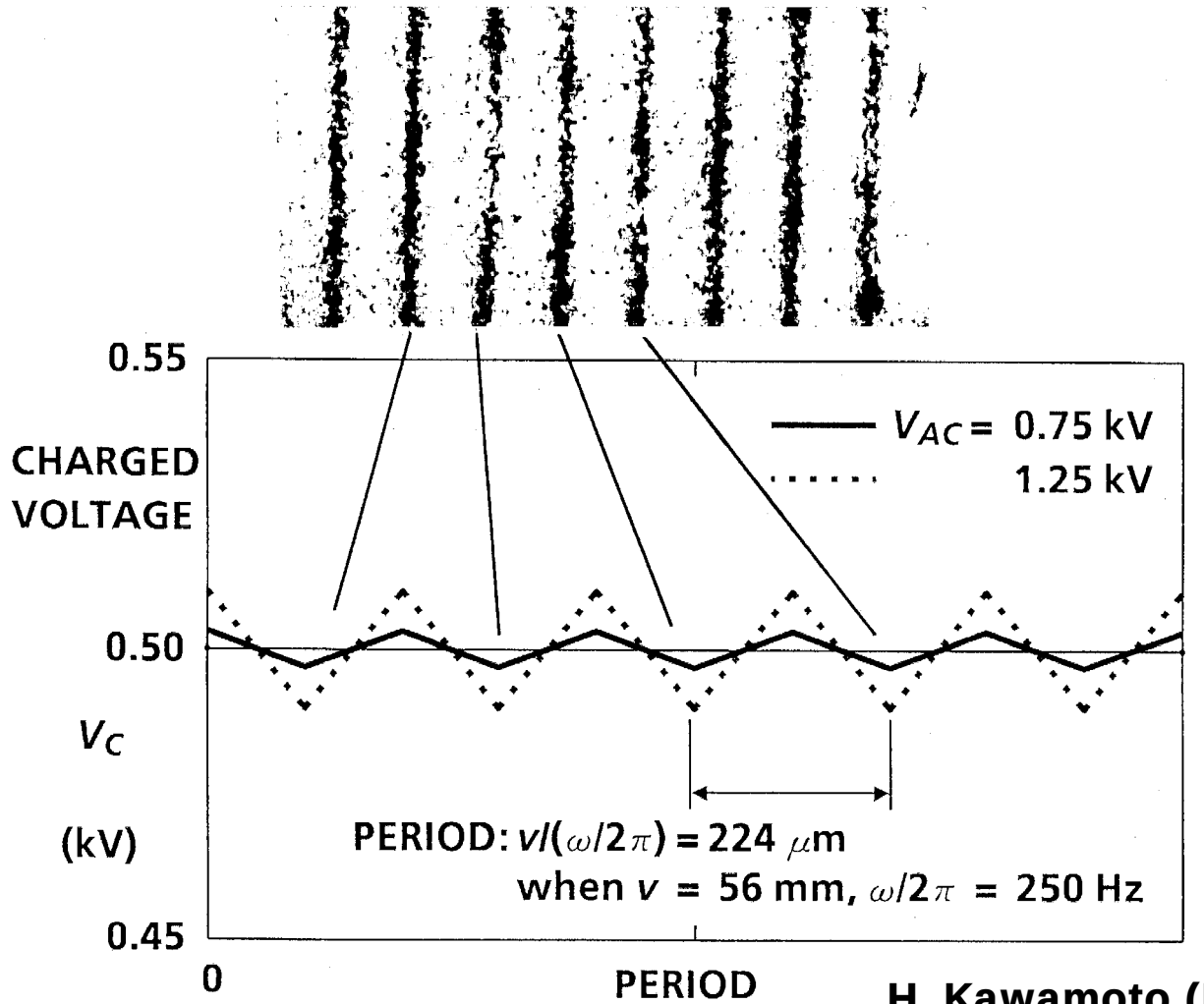
H. Kawamoto (Fuji Xerox) 1993



Calculated and Measured Charging Characteristics

H. Kawamoto (Fuji Xerox) 1993

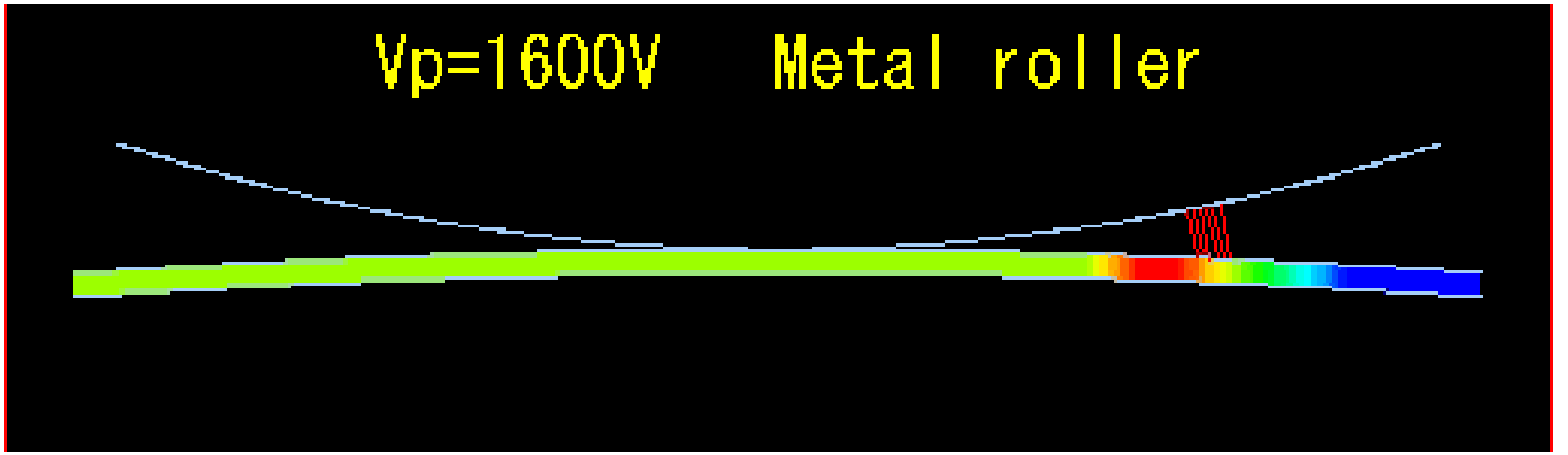
Analysis of Strip Image Defect due to AC Voltage Application



H. Kawamoto (Fuji Xerox) 1993

Analysis of Image Defect due to DC Voltage Application

contact roller

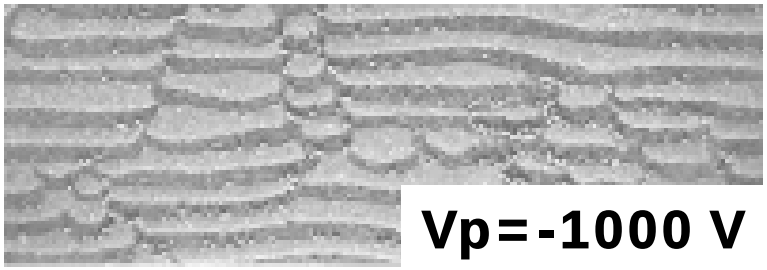


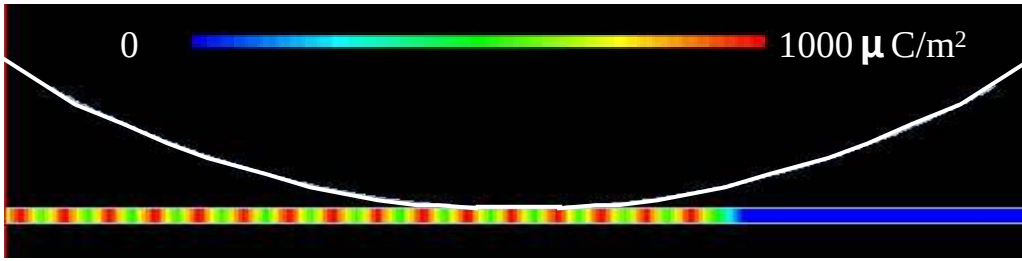
OPC

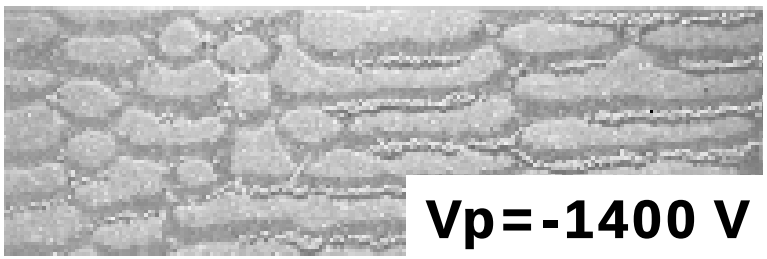
- expanded to 2D field
- circumferential transport of charge

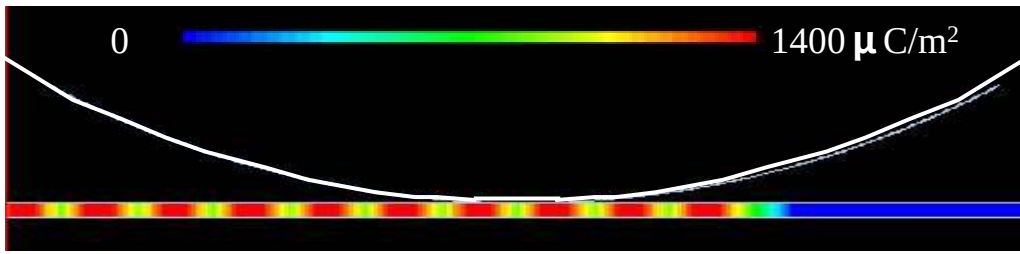
M. Kadonaga (Ricoh) 1999

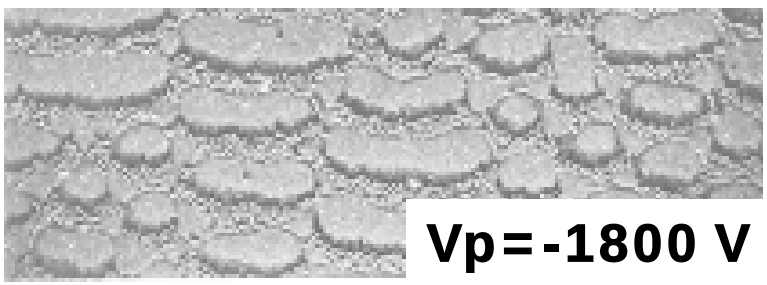
Analysis of Image Defect due to DC Voltage Application

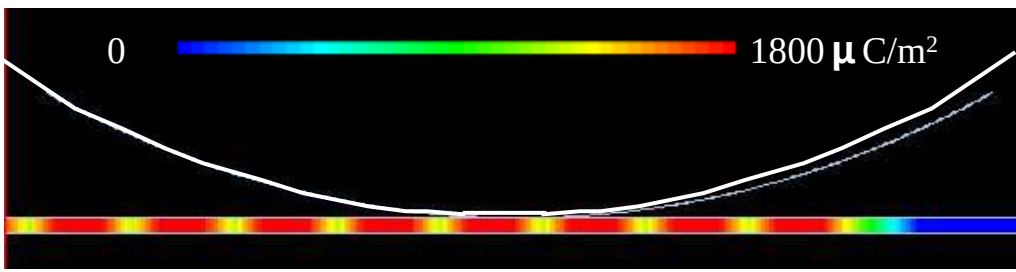












observed image defect **calculated charge density**

M. Kadonaga (Ricoh) 1999

Plasma Ozone Synthesis

Ozone Synthesis

$$e^- + O_2 \rightarrow 2O + e^- \qquad O + O_2 + O_2 \rightarrow O_3 + O_2$$

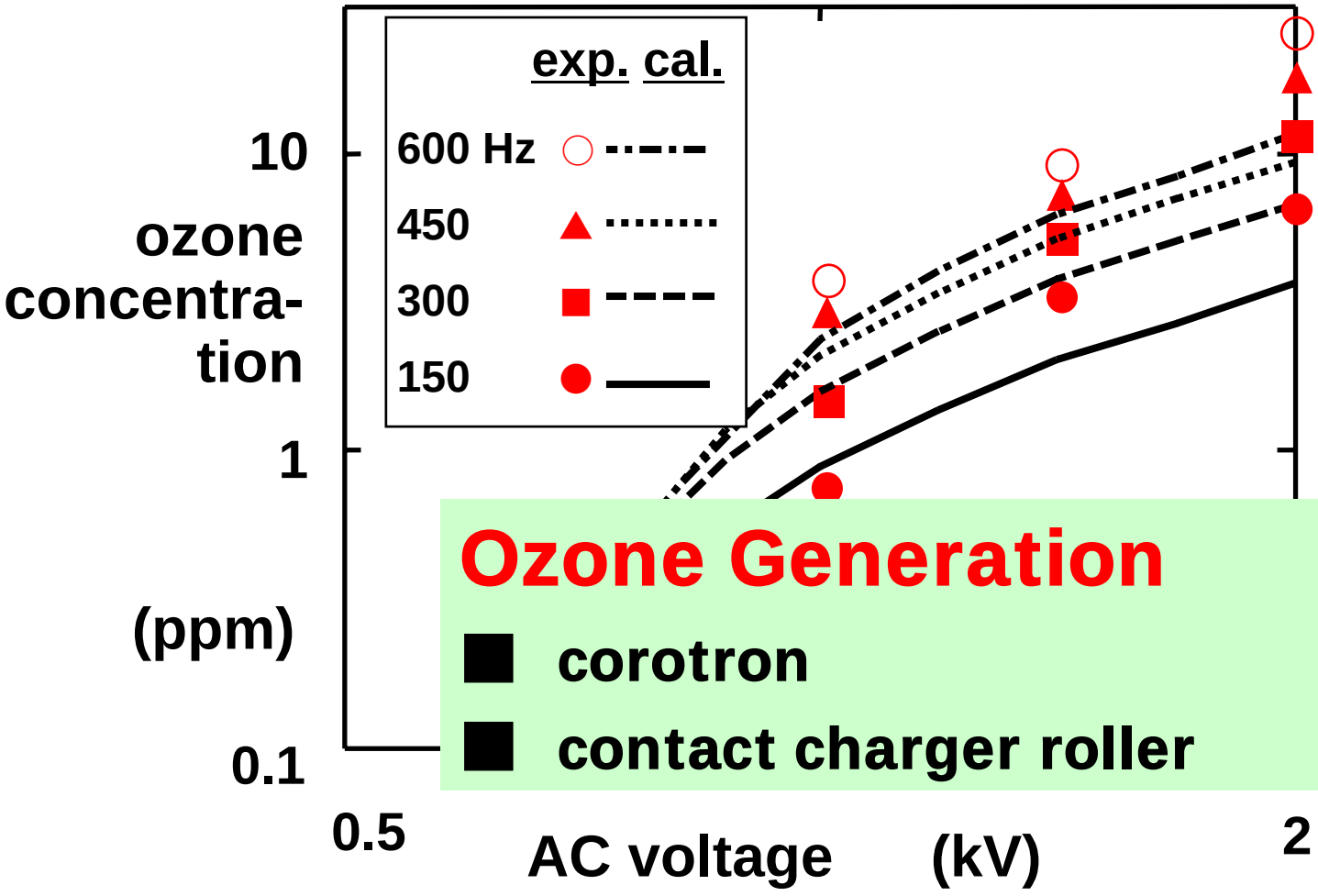
Plasma Reaction Rate

$$S = 2\pi \int_{r_o}^{R} K_r n_e n_o r dr \qquad (O_3/sec)$$

- based on Townsend theory

H. Kawamoto (Fuji Xerox) 1994

Measured and Calculated Ozone Concentration



Ozone Generation

corotron	100
contact charger roller	2

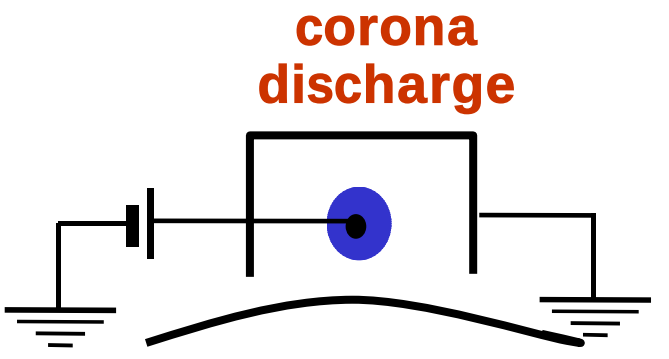
H. Kawamoto (Fuji Xerox) 1994

Modeling of Corona Charging

- **conservation of charges**

$$\frac{\partial n_p}{\partial t} + div\left(\mu_p E n_p\right) = -R_e n_p n_n$$

$$\frac{\partial n_n}{\partial t} + div\left(-\mu_n E n_n\right) = -R_e n_p n_n$$



- **Poisson's equation**

$$div\left(\varepsilon E\right) = e\left(n_p - n_n\right)$$

- **boundary condition**

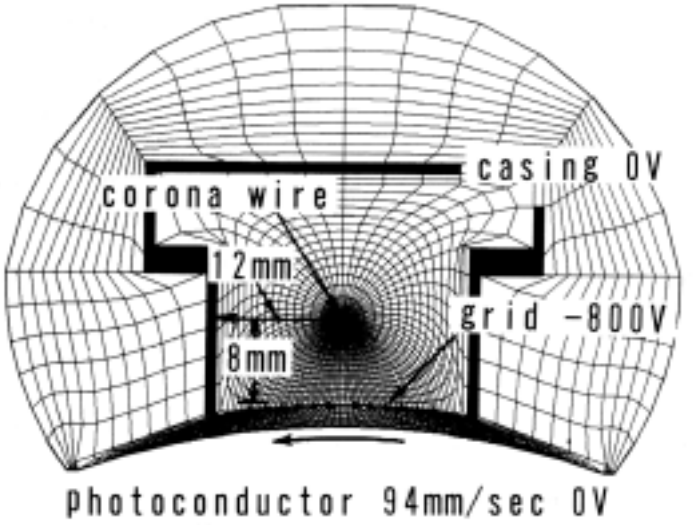
$E = E_{p0}$ (threshold of corona onset) at wire

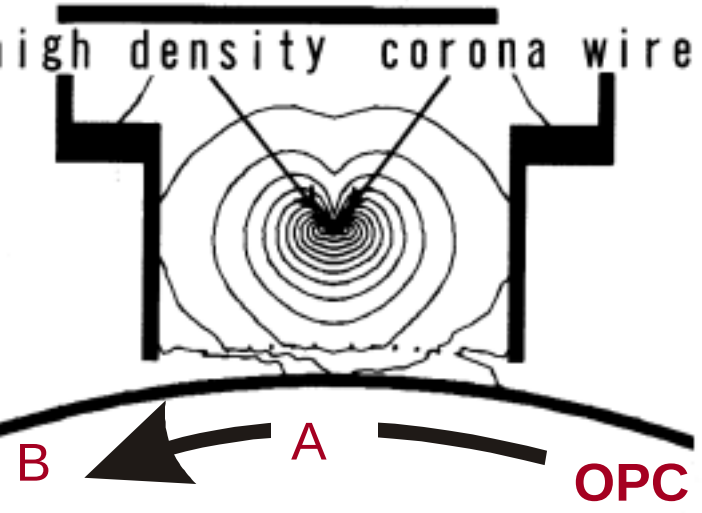
Numerical Result

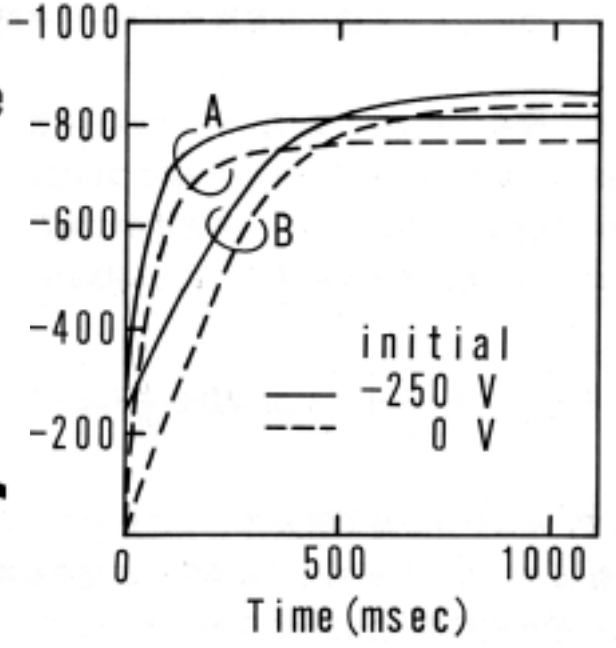
effects of rotation and resistivity of OPC

$$J_p = \sigma E + \rho v_0$$

$$\frac{\partial \rho}{\partial t} + div\, J_p = 0$$







initial 0 V
cal. −863 V
exp. −900 V

initial −250 V
cal. −886 V
exp. −925 V

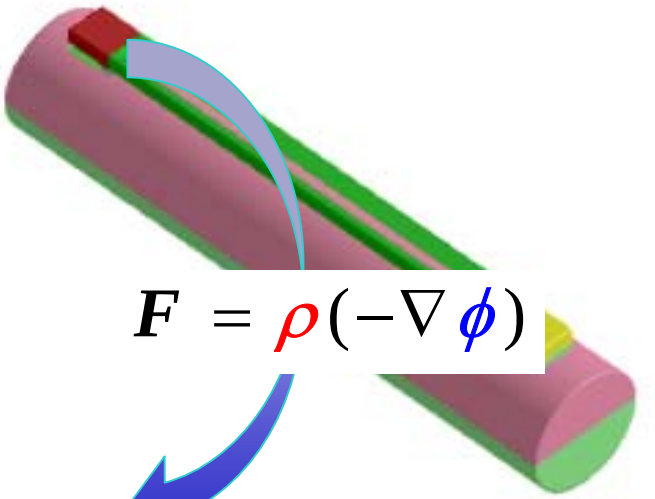
Y. Watanabe (Ricoh) 1990

Flow Analysis of Ionic Wind

■Discharge Field (2D, unipolar)

$$\frac{\partial \rho}{\partial t} + \nabla\left(\mu\rho\left(-\nabla\phi\right)\right) = 0$$

$$\nabla\left(\varepsilon\left(-\nabla\phi\right)\right) = \rho$$

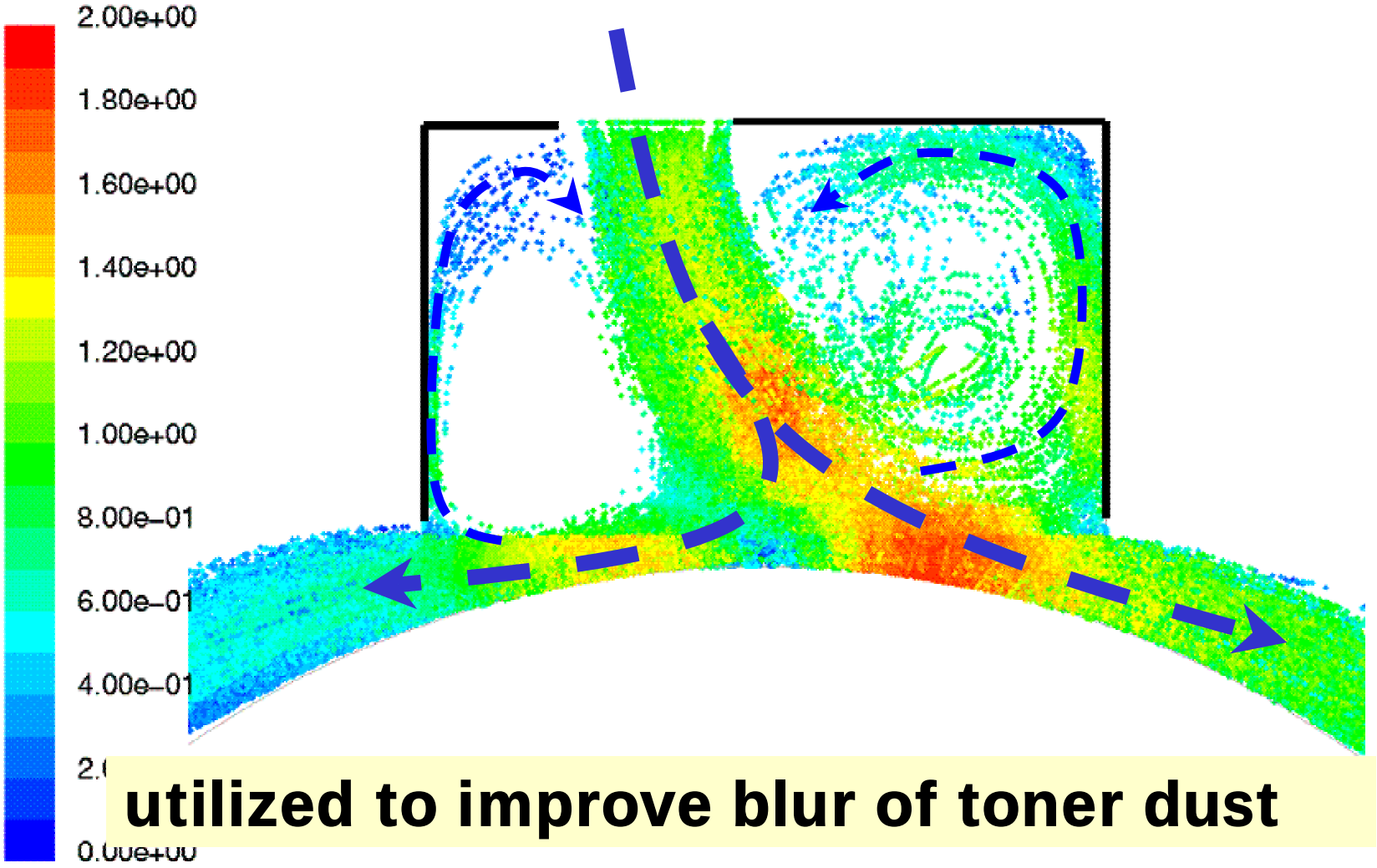


■Aerodynamics (3D)

$$\frac{\partial \rho_g \boldsymbol{u}}{\partial t} + \rho_g\left(\boldsymbol{u}\cdot\nabla\right)\boldsymbol{u} = -\nabla p + \mu_g \Delta \boldsymbol{u} + \boldsymbol{F}$$

Navier-Stokes

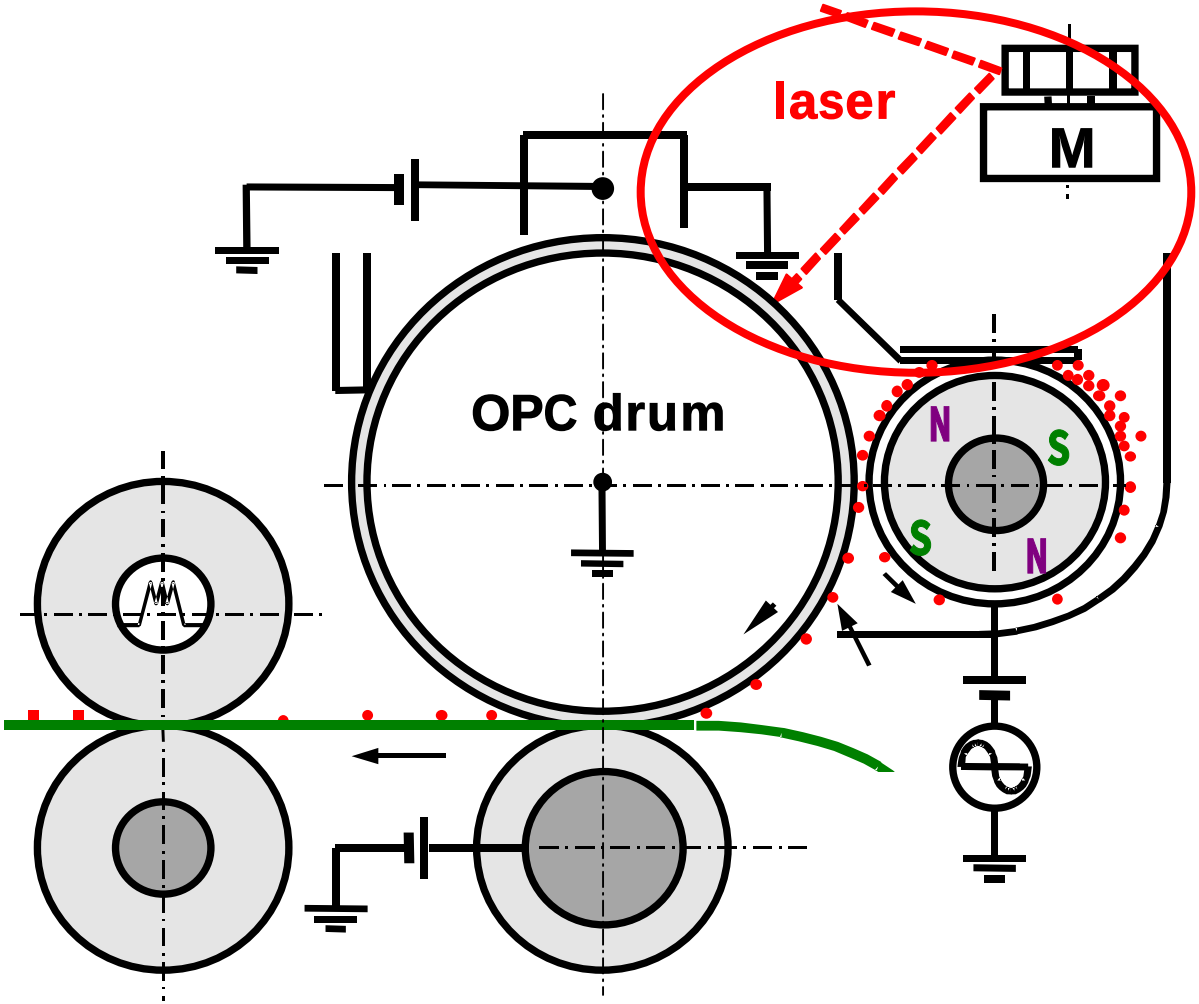
Calculated Velocity Distribution



utilized to improve blur of toner dust

H. Okamoto (Fuji Xerox) 2002

2. Exposure



Formation of Latent Image
(3D, time-dependent, 3-unknowns)

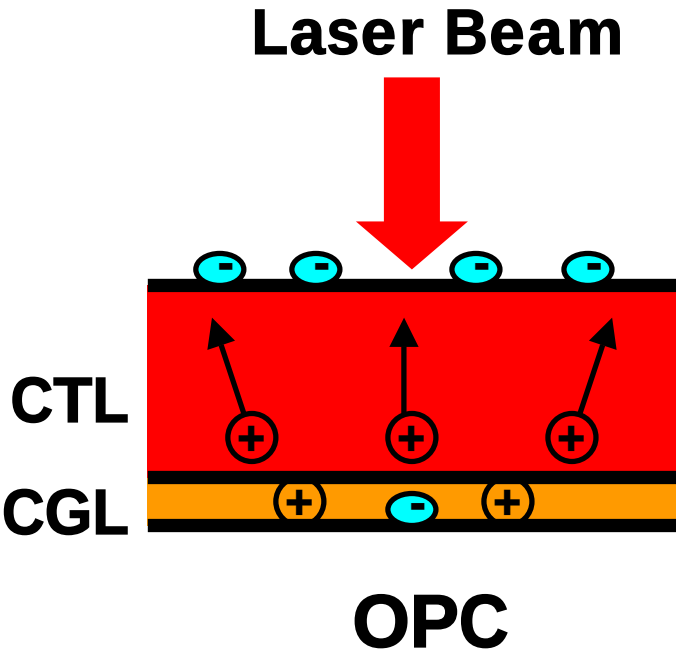
■ conservation of charges

$$\frac{\partial n_p}{\partial t} + div(\mu_p E n_p) = \Gamma - R_e n_p n_n$$

$$\frac{\partial n_n}{\partial t} - div(\mu_n E n_n) = \Gamma - R_e n_p n_n$$

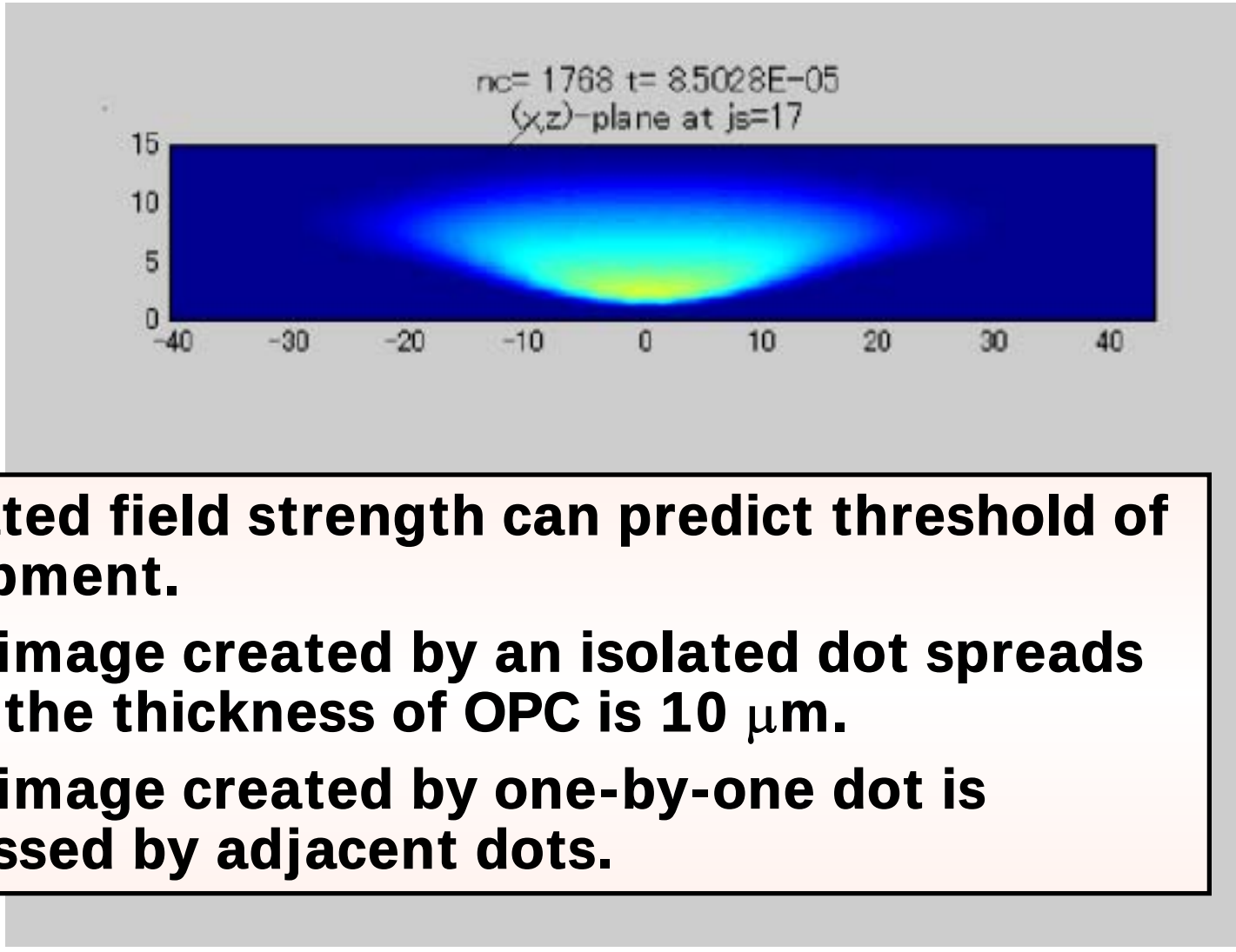
■ Poisson'Equation

$$div(\varepsilon E) = e(n_p - n_n)$$



Calculated Transient Charge Distribution

main scan

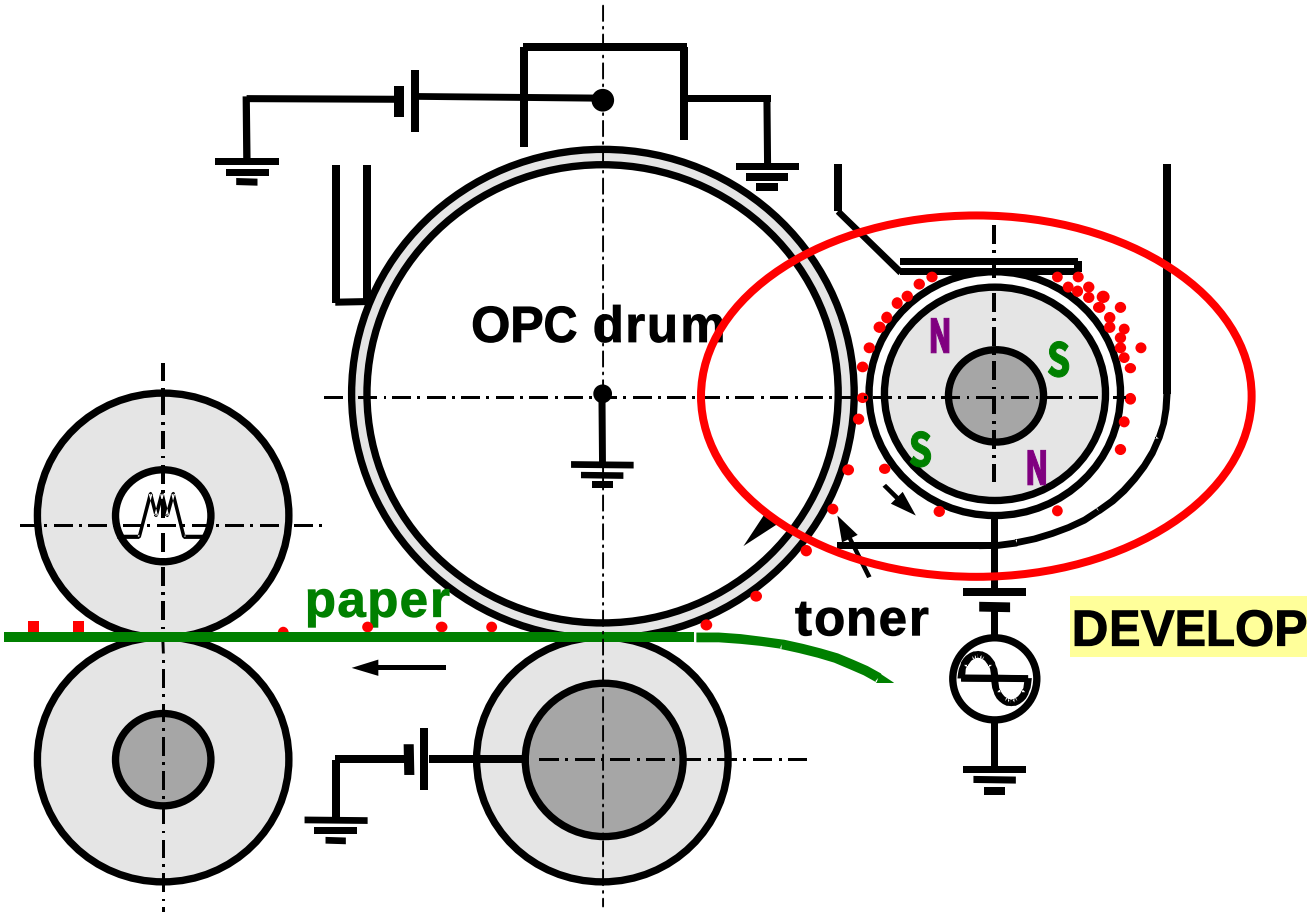


- **Calculated field strength can predict threshold of development.**
- **Latent image created by an isolated dot spreads even if the thickness of OPC is 10 μm.**
- **Latent image created by one-by-one dot is suppressed by adjacent dots.**

beam size: 30 μm

Y. Watanabe (Ricoh) 2000

3. Development



Two Approaches for Toner/Carrier Dynamics

- **Continuous Model**

  Navier-Stokes

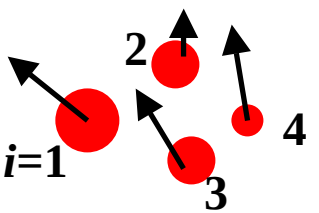
  - (Hitachi Printing, Ricoh, Fuji Xerox, ---), 2000

- **Discrete Model**

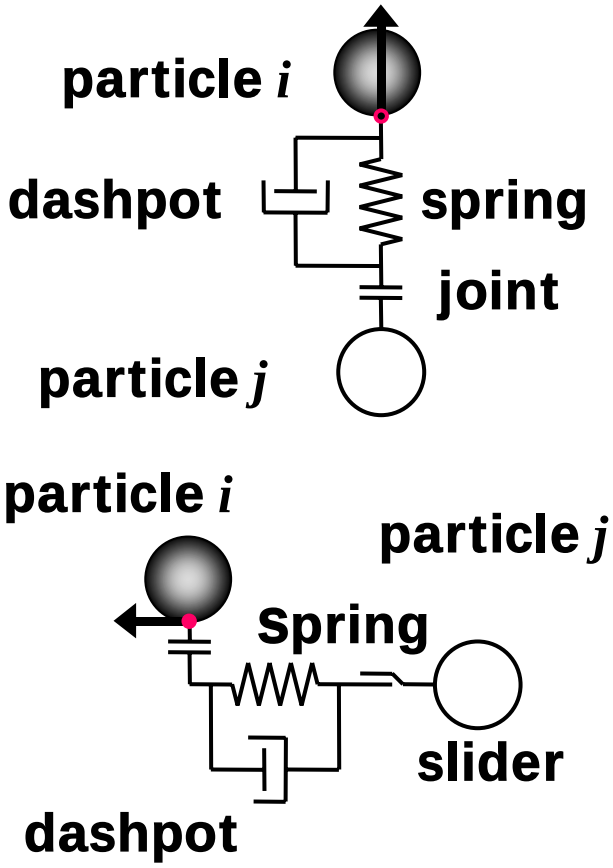
  Discrete Element Method (DEM)

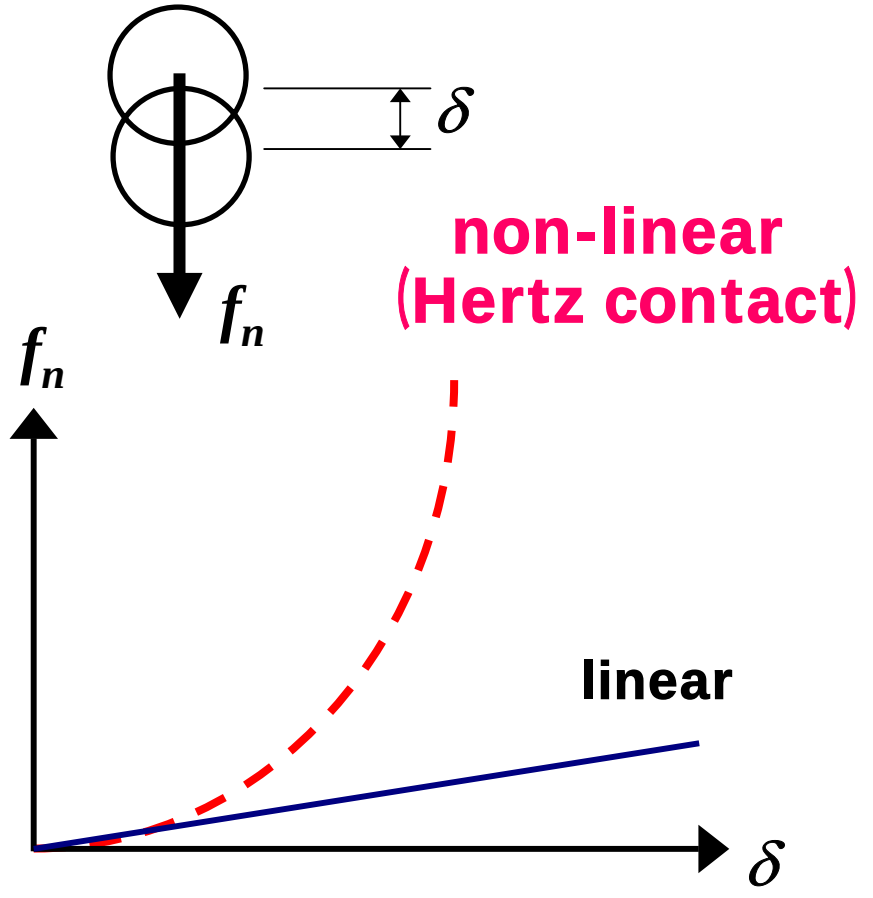
$$m_i \ddot{x}_i + c_i \dot{x}_i + k_i x_i = F_{mechanical} + F_{electrostatic} + F_{magnetic} +$$

$$x = (x, y, z, \theta_x, \theta_y, \theta_z)$$



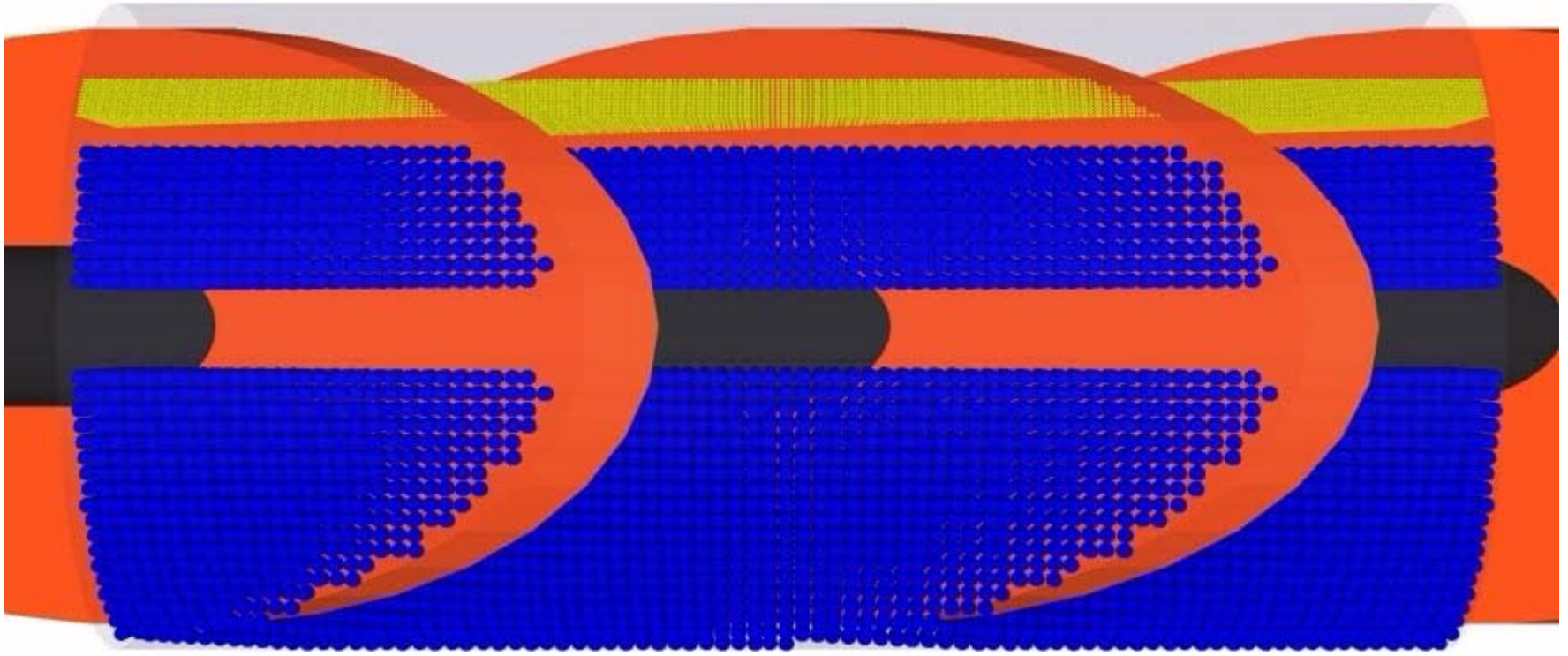
Mechanical Interaction





Mechanical Interaction between Beads (Voigt model)

Mixing of Toner and Carrier Particles in Auger



H. Mio (Kyoto Fine Particle Technology) 2007

Magnetic Interaction

- **magnetic force**

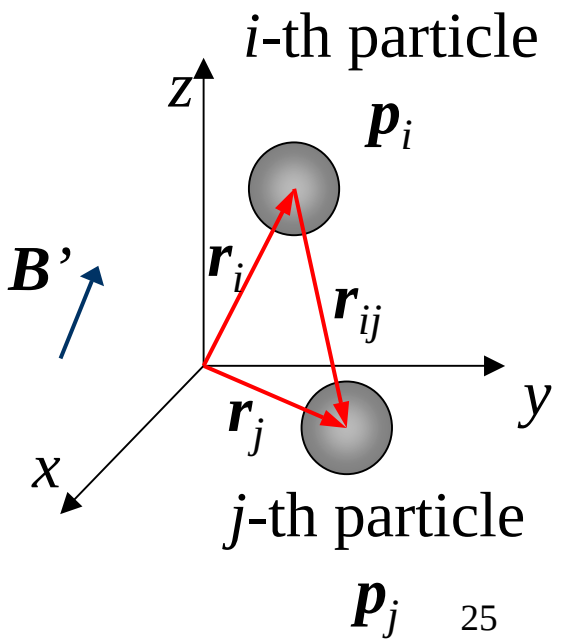
$$\boldsymbol{f}_{mj} = (\boldsymbol{p}_j \cdot \nabla)\boldsymbol{B}_j, \quad \boldsymbol{M}_{mj} = \boldsymbol{p}_j \times \boldsymbol{B}_j$$

- **magnetic dipole moment**

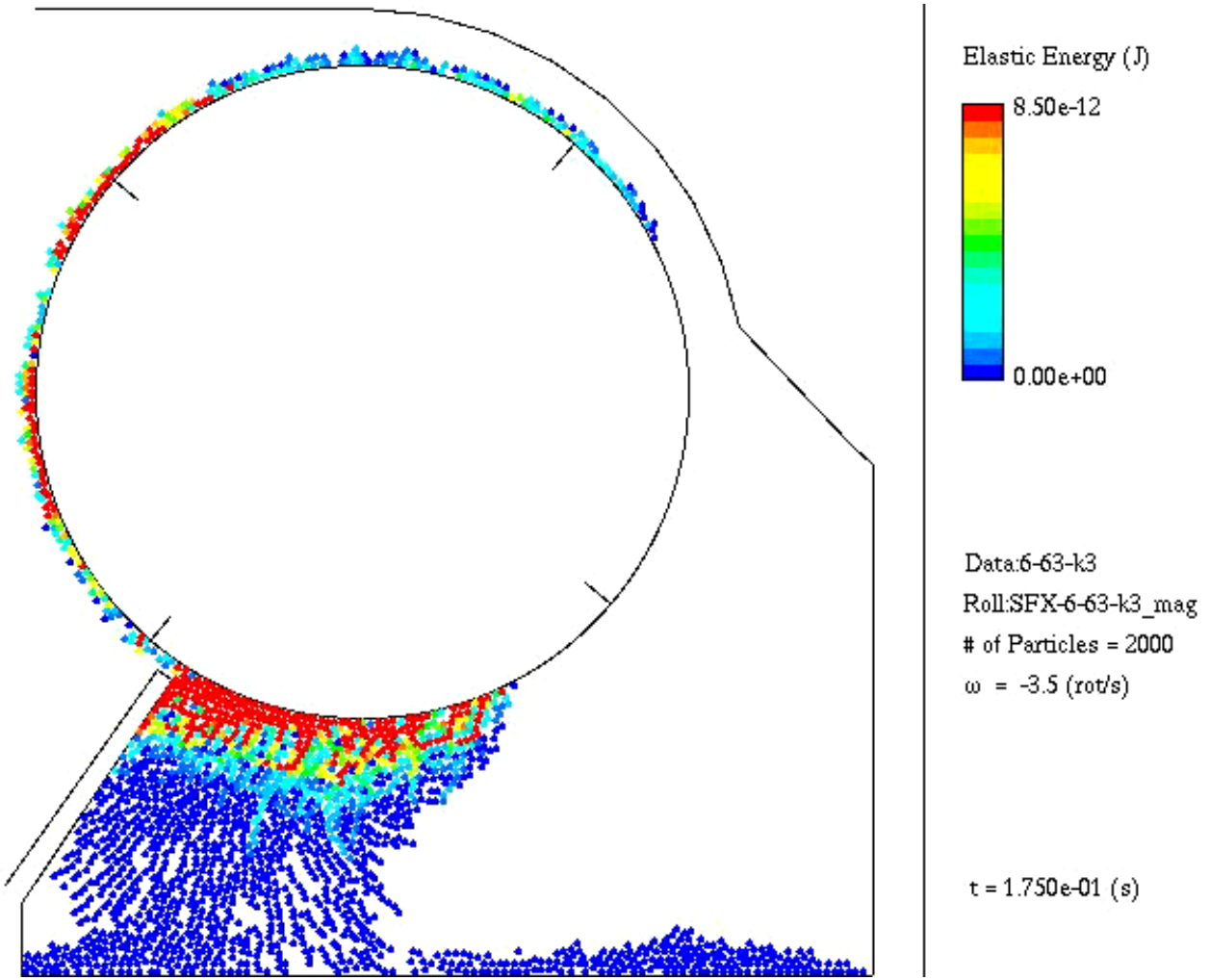
$$\boldsymbol{p}_j = \frac{4\pi}{\mu_0}\frac{\mu-1}{\mu+2}\frac{a_j^{\,3}}{8}\boldsymbol{B}_j' + \frac{\mu-1}{\mu+2}\frac{a_j^{\,3}}{8}\sum_{\substack{i=1 \\ j\neq i}}^{N}\left(3\frac{\boldsymbol{p}_i \cdot \boldsymbol{r}_{ij}}{|\boldsymbol{r}_{ij}|^5}\boldsymbol{r}_{ij} - \frac{\boldsymbol{p}_i}{|\boldsymbol{r}_{ij}|^3}\right)$$

due to mag.roller

due to other particles



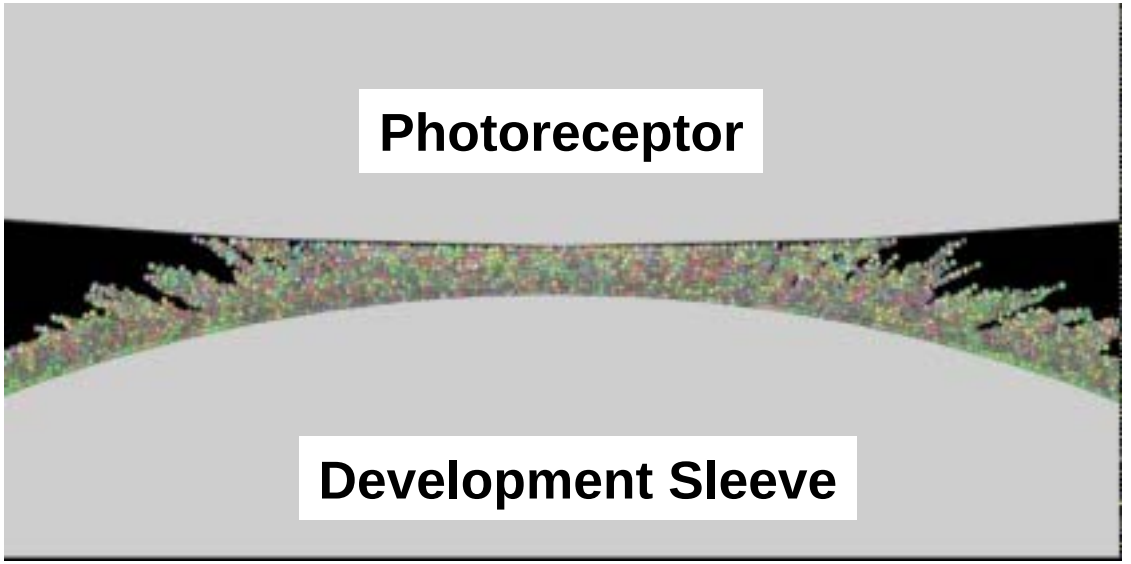
Design of Magnetic Roller



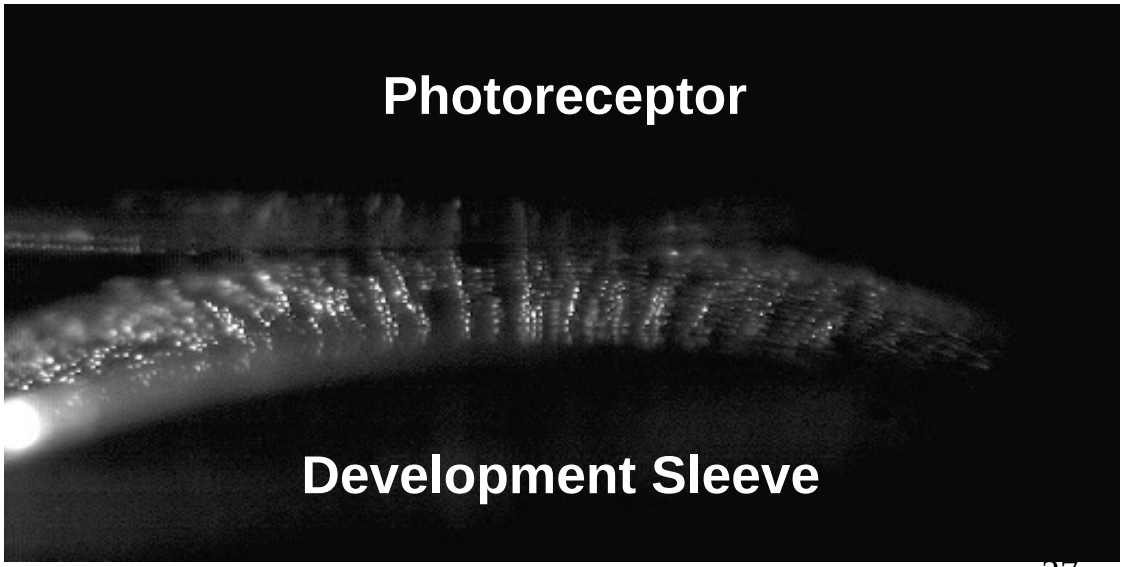
utilized to improve pole pattern of magnetic roller that can efficiently mix toner/carrier particles.

Magnetic Brushes

Simulation



Experiment

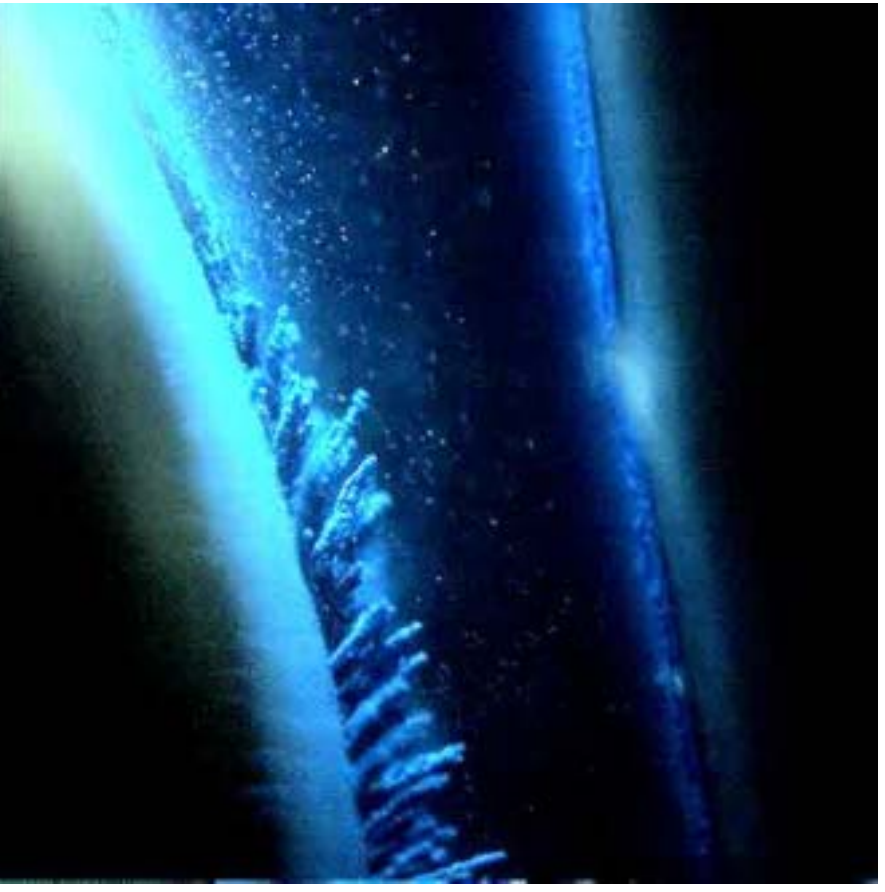


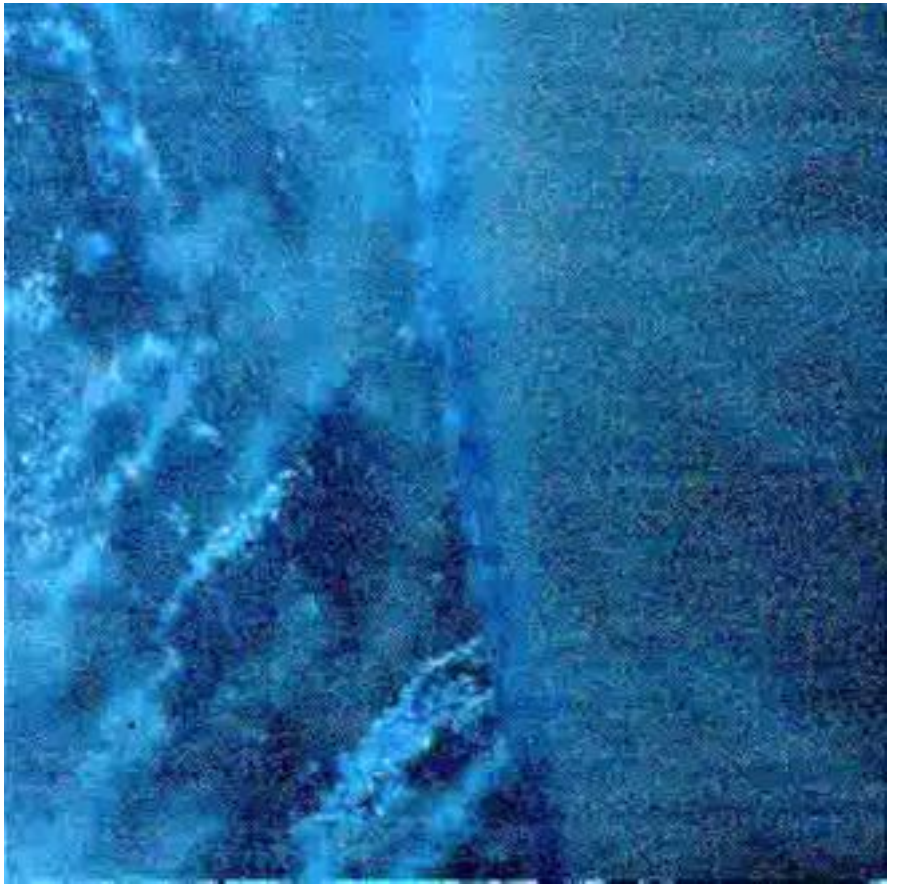
H. Kawamoto (Waseda) 2007

Two-Component Development

H. Mio (Kyoto Fine Particle Technology) 2007

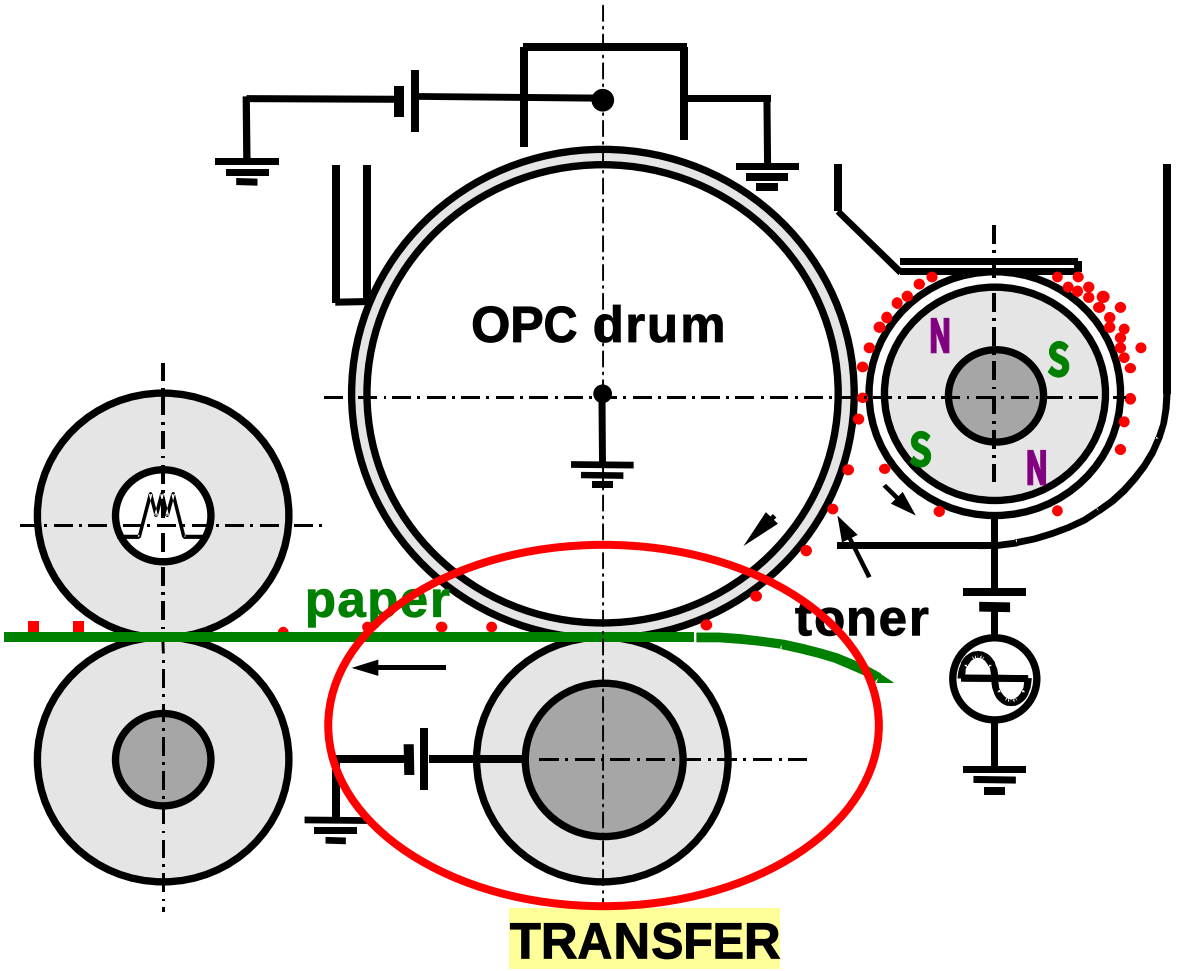
Direct Observation of Development by High Speed Camera



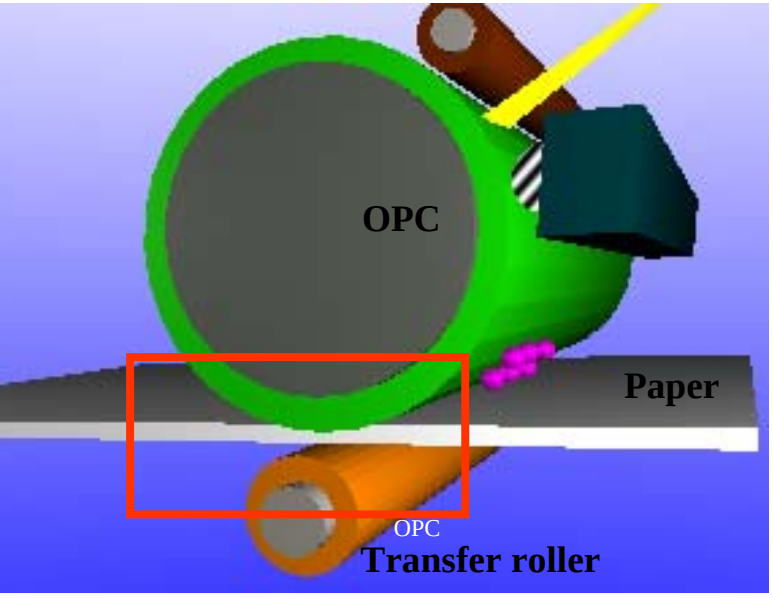


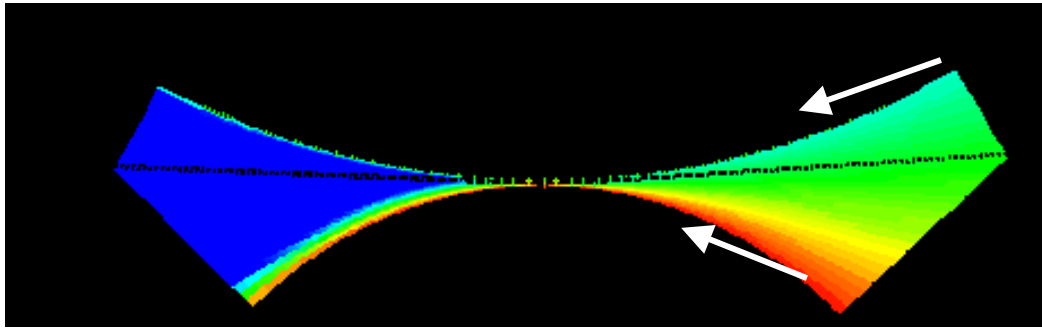
H. Kawamoto (Waseda) 2007

4. Transfer

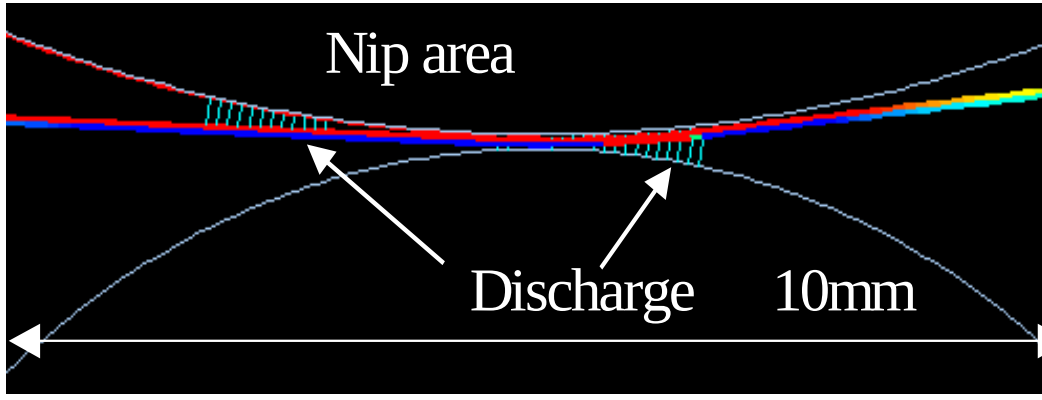


Electrostatic Field in Transfer Process



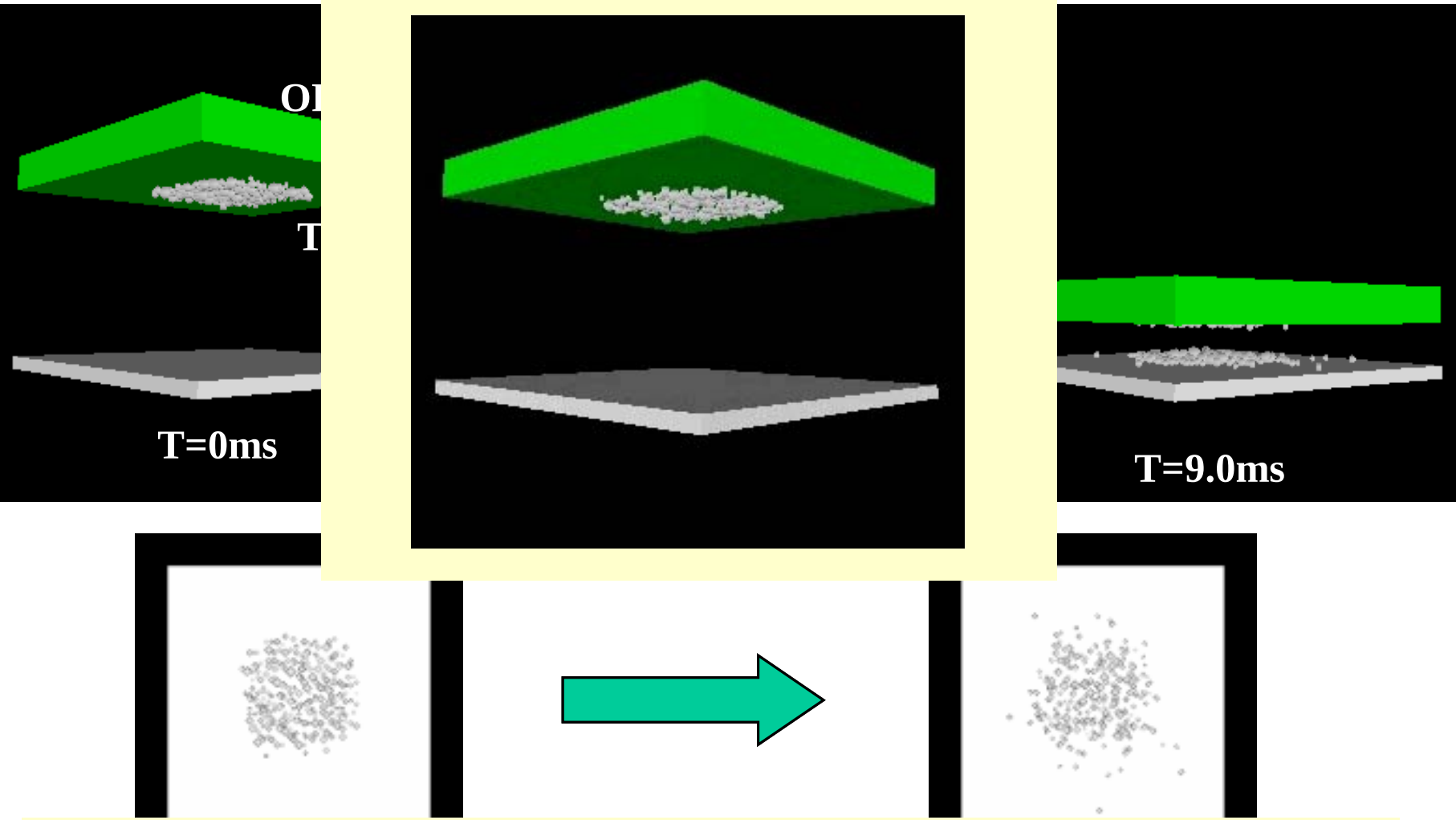


potential distribution



discharge

Toner Dynamics in Roller Transfer System

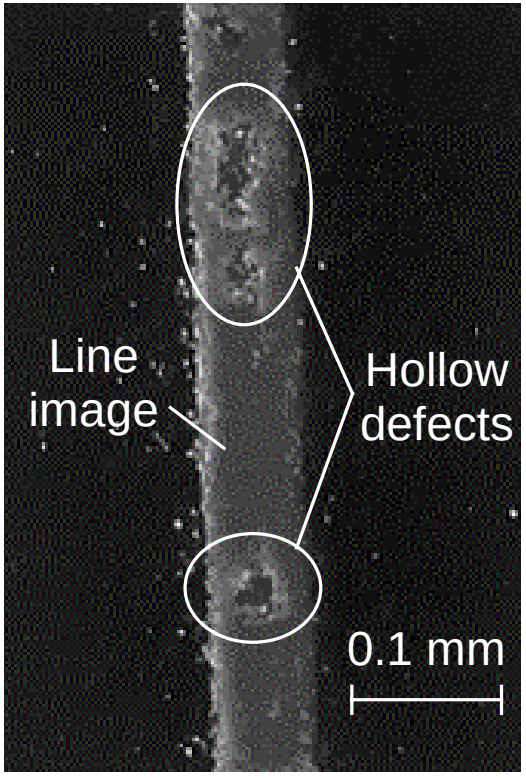


Toner particles scatter due to electrical discharge.

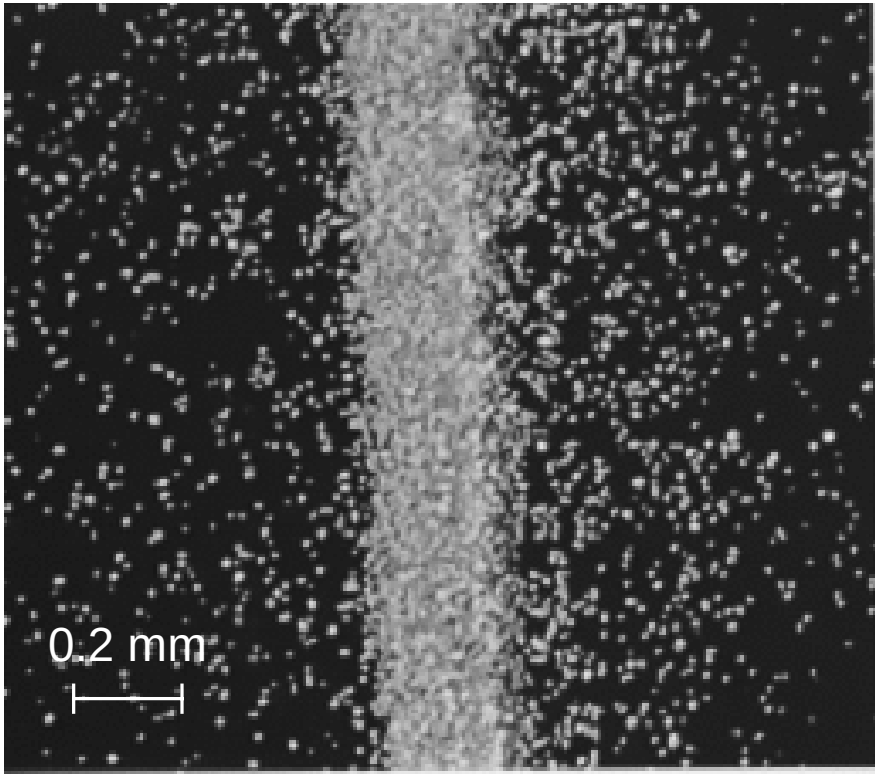
on OPC **on paper**

M. Kadonaga (Ricoh) 2004

Hollow Defect and Toner Scattering

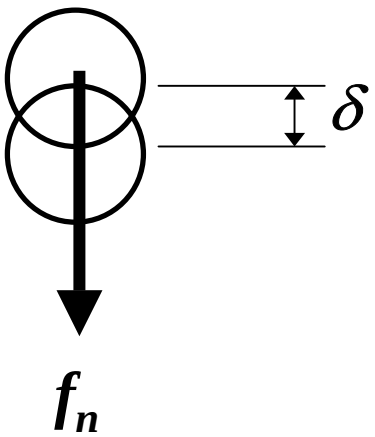


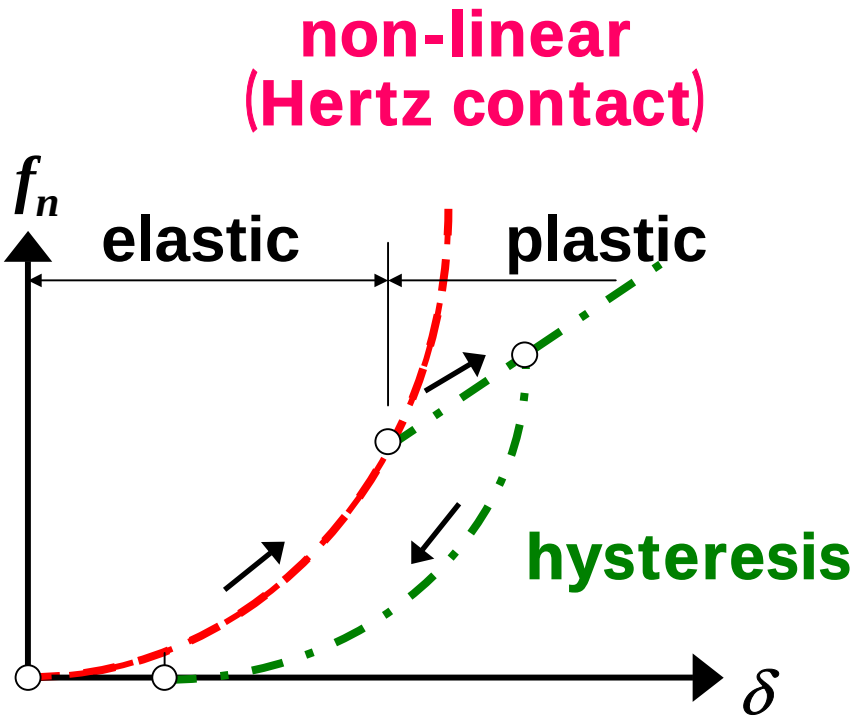
hollow defect



toner scattering

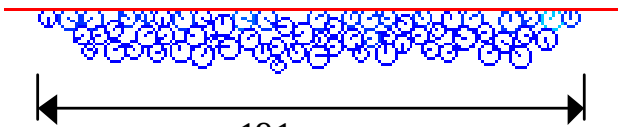
Hysteresis of Toner Compression



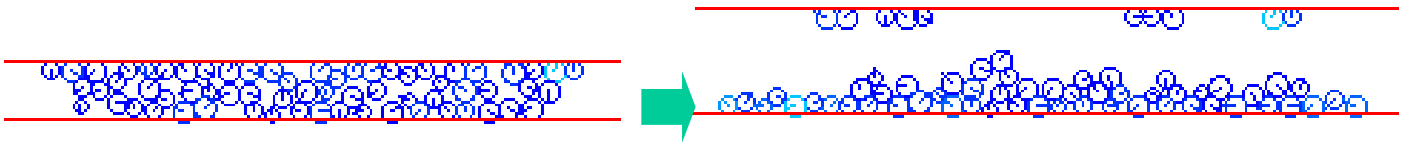


N. Nakayama (Fuji Xerox) 1997

Hollow Defect and Toner Scattering

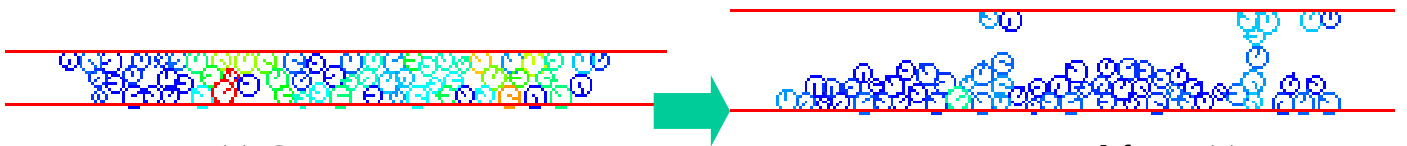


on OPC (before transfer)



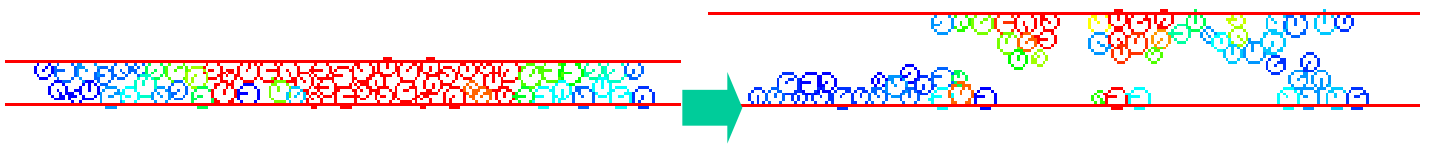
(b) Compressed **low compression** **toner scattering**

(ε_h=0.045, p=0.7 kPa) (λ=84.6 %)



(c) Comp **medium compression** red from (c)

(ε_h=0.134, p=31.7 kPa) (λ=83.2 %)

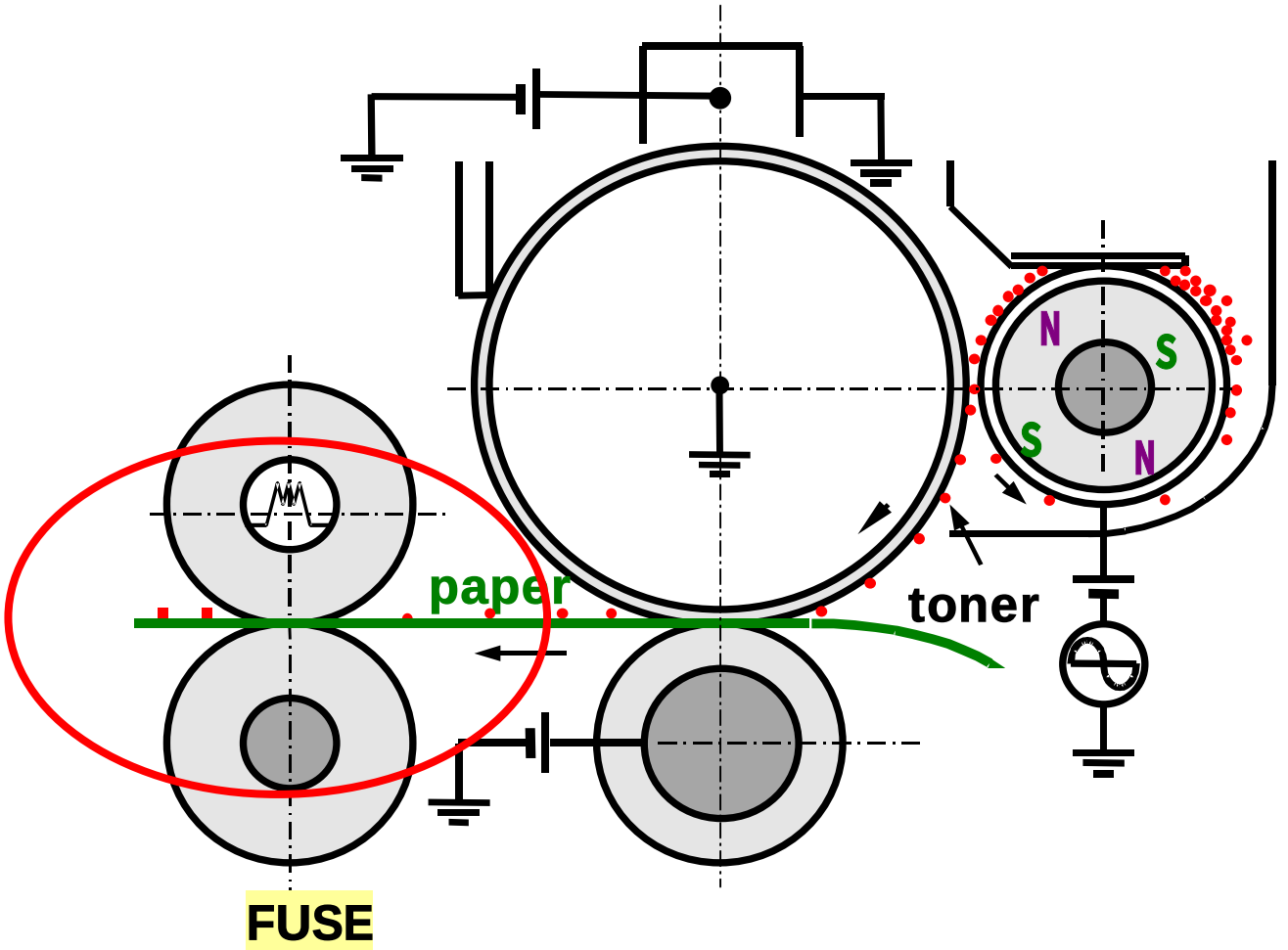


(d) Compressed **high compression** **hollow defect**

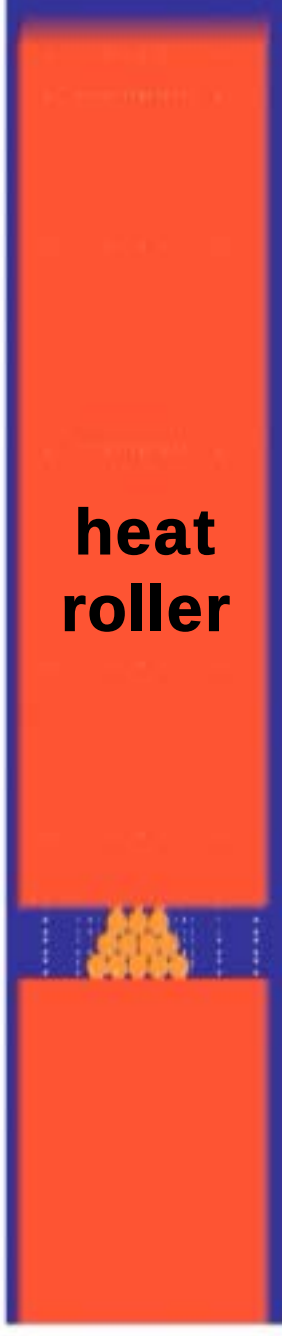
(ε_h=0.259, p=168.8 kPa) (λ=46.2 %)

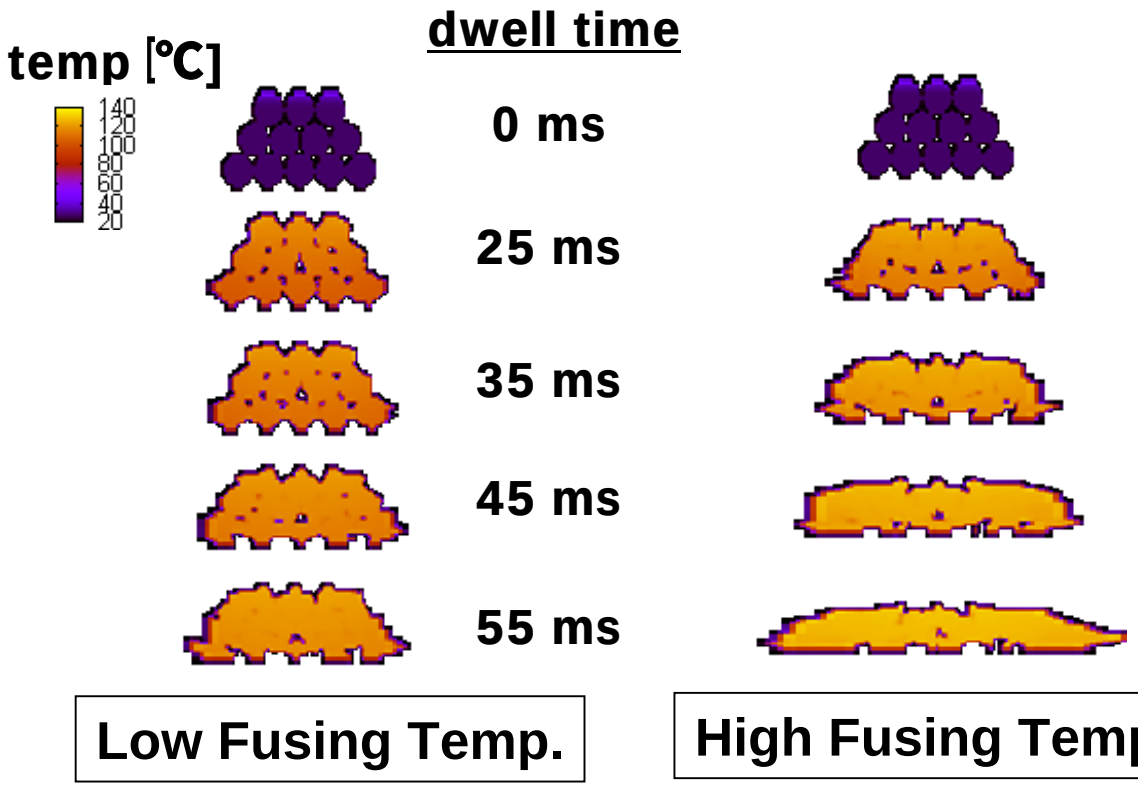
N. Nakayama (Fuji Xerox) 1997

5. Fusing



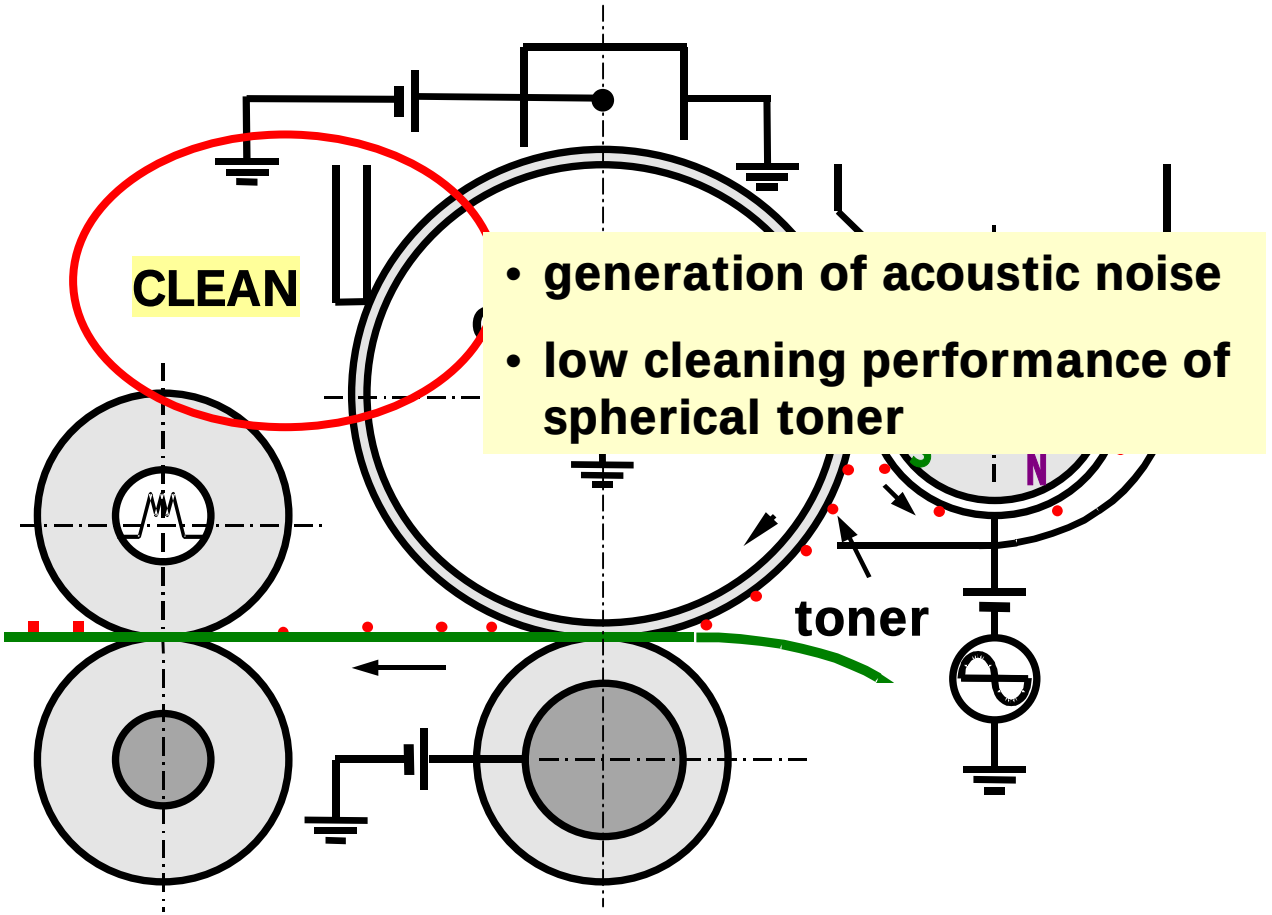
Visco-Elasticity of Toner



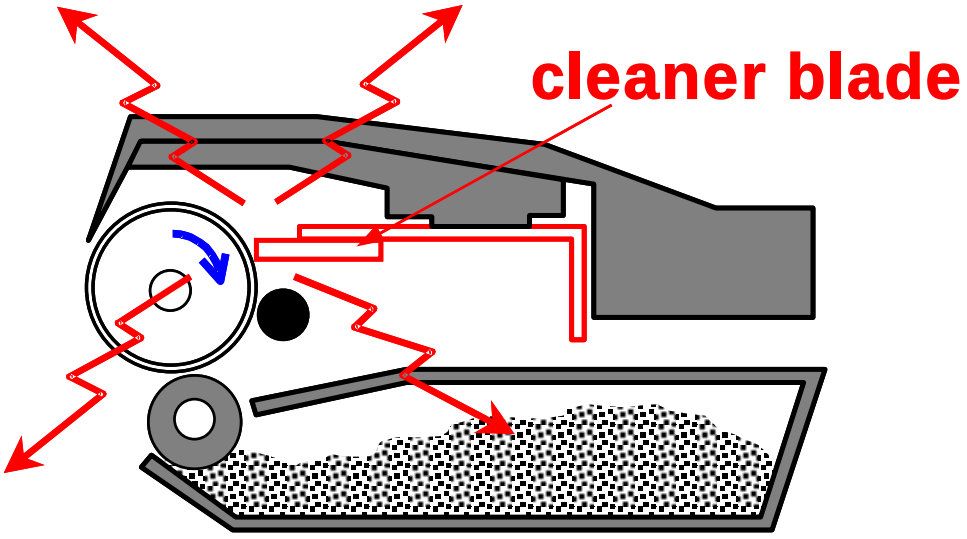


S. Hasebe (Fuji Xerox) 2007

6. Cleaning


CLEAN
• generation of acoustic noise
• low cleaning performance of spherical toner
N
toner

Acoustic Noise from Cleaner Blade



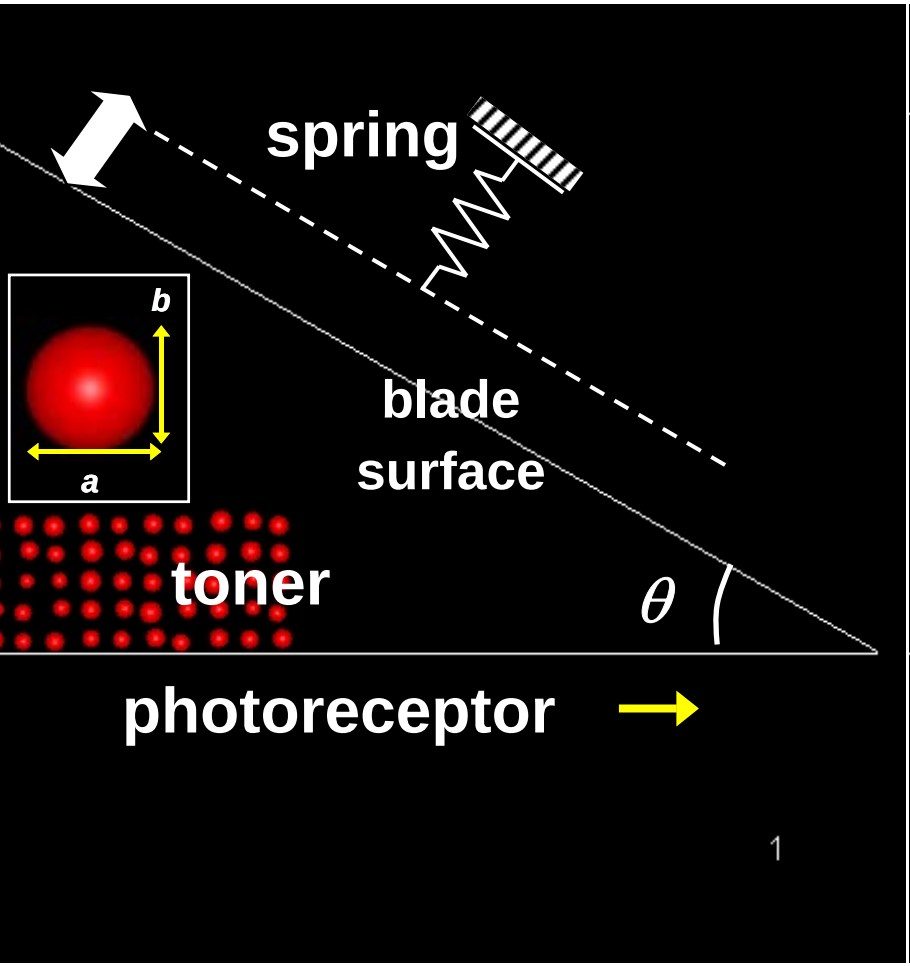
- **Low Speed**
  - **stick-slip**

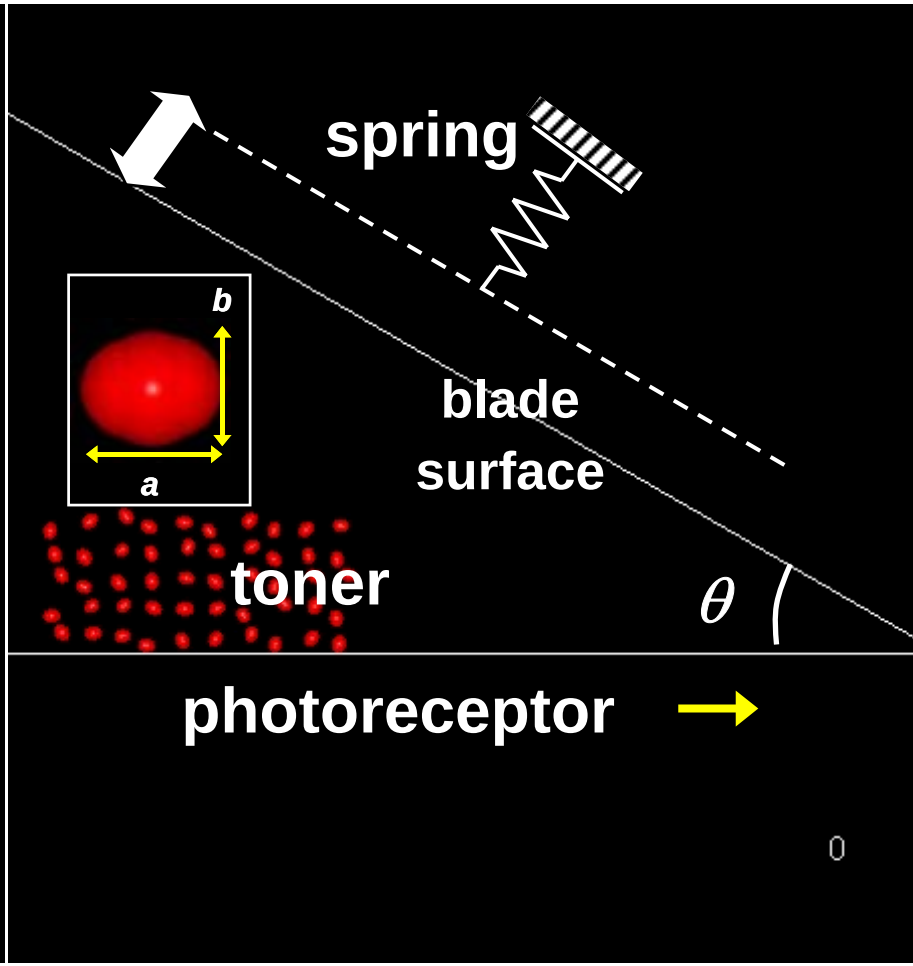
H. Kawamoto (Fuji Xerox) 1995

- **Rated Speed**
  - **coupled non-linear vibration**

M. Kasama (Fuji Xerox) 2006

Cleaning Performance of Spherical Toner Particles



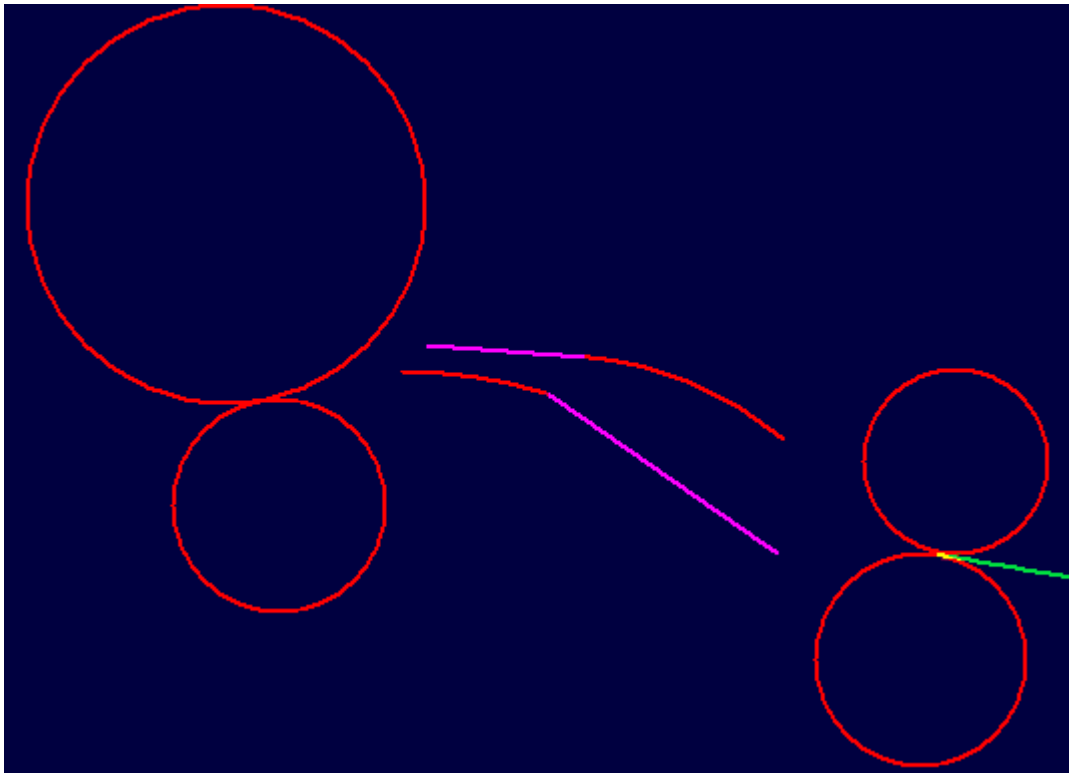


μ =0.96, θ =30deg, k_w=10N/m,
***a*/*b*=1.0**

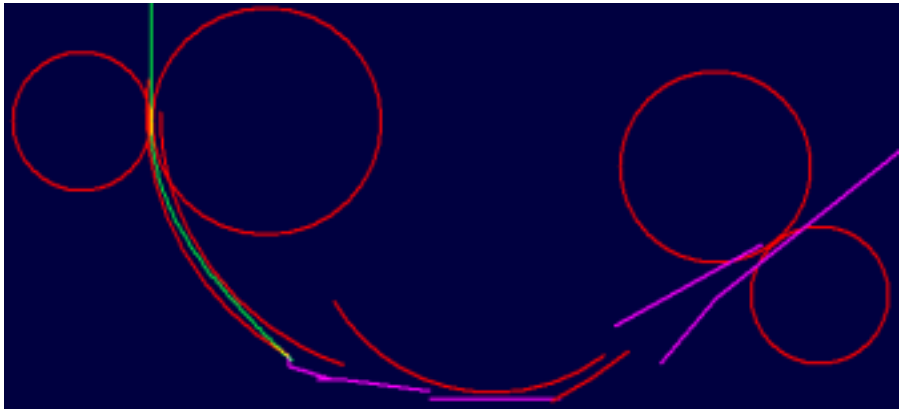
μ =0.96, θ =30deg, k_w=10N/m,
***a*/*b*=1.23**

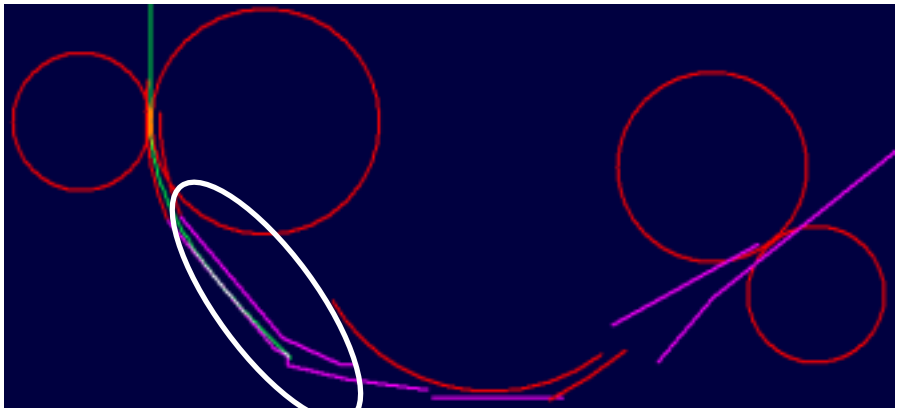
N. Nakayama (Fuji Xerox) 2004

7. Paper Handling



Improvement of Paper Path for Image Scanner

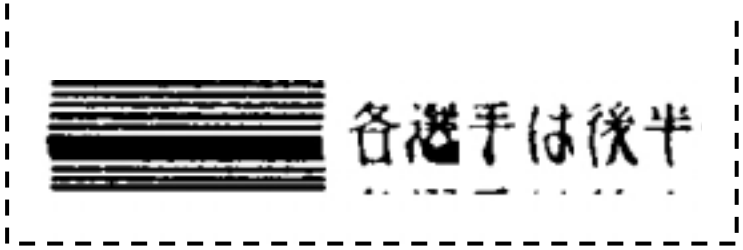


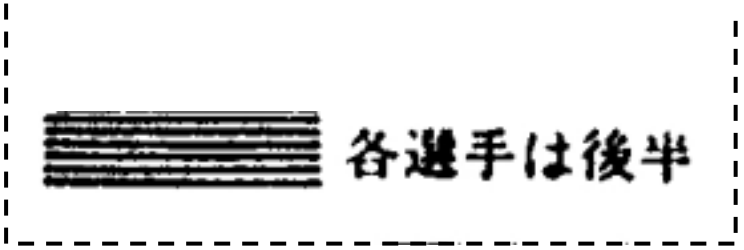


reader

reader

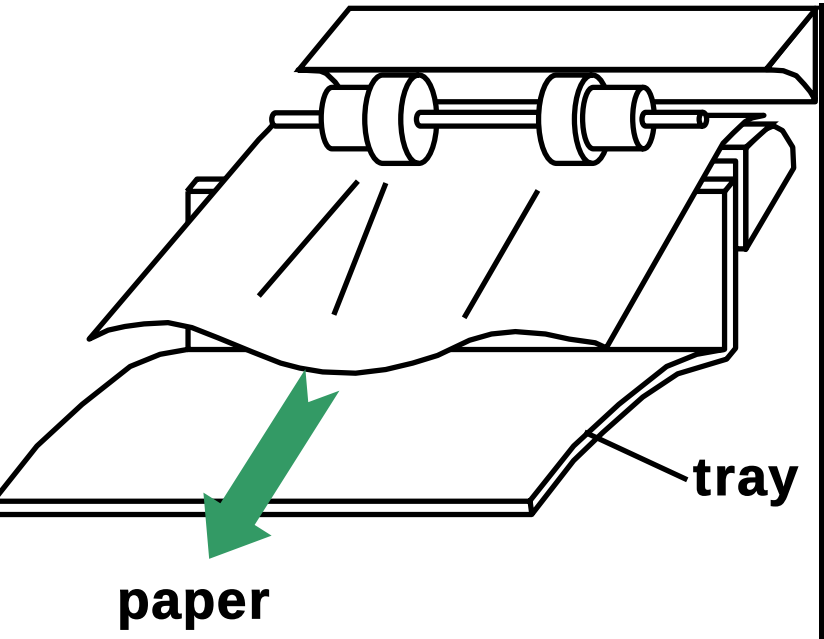
output image

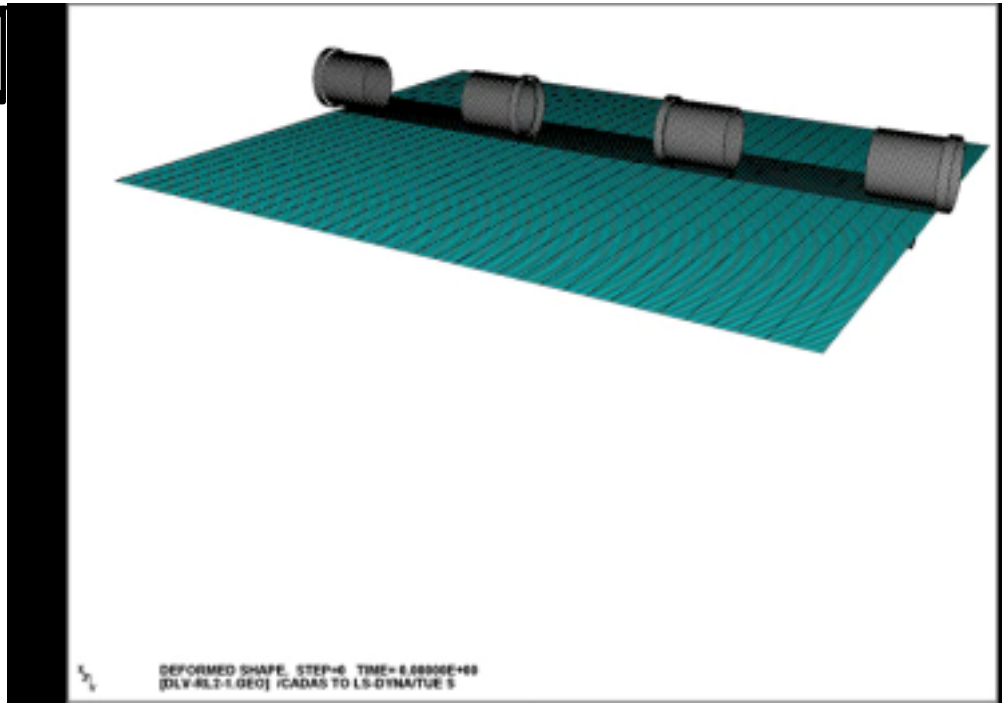




O. Takehira (Ricoh) 2000

Application for Paper Feeder





Promotion of Simulation Technology and Education of Young Engineers in Japan

Academic Committees

Three Japanese academic committees to promote the modeling and numerical simulation of electrophotography processes

- **The Imaging Society of Japan (ISJ)**
  - **education of young engineers**
  - **publish of textbook**
- **The Japan Society of Mechanical Engineers (JSME)**
  - **technology exchange on a give-and-take basis**
- **The Japan Society for Precision Engineering (JSPE)**
  - **paper handling**

Simulation Seminar

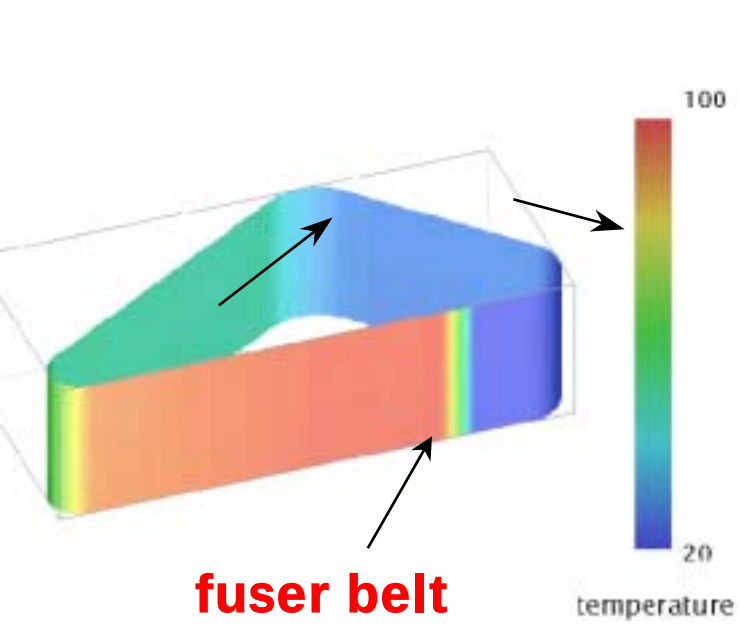
The seminar is conducted every year for 15 students.

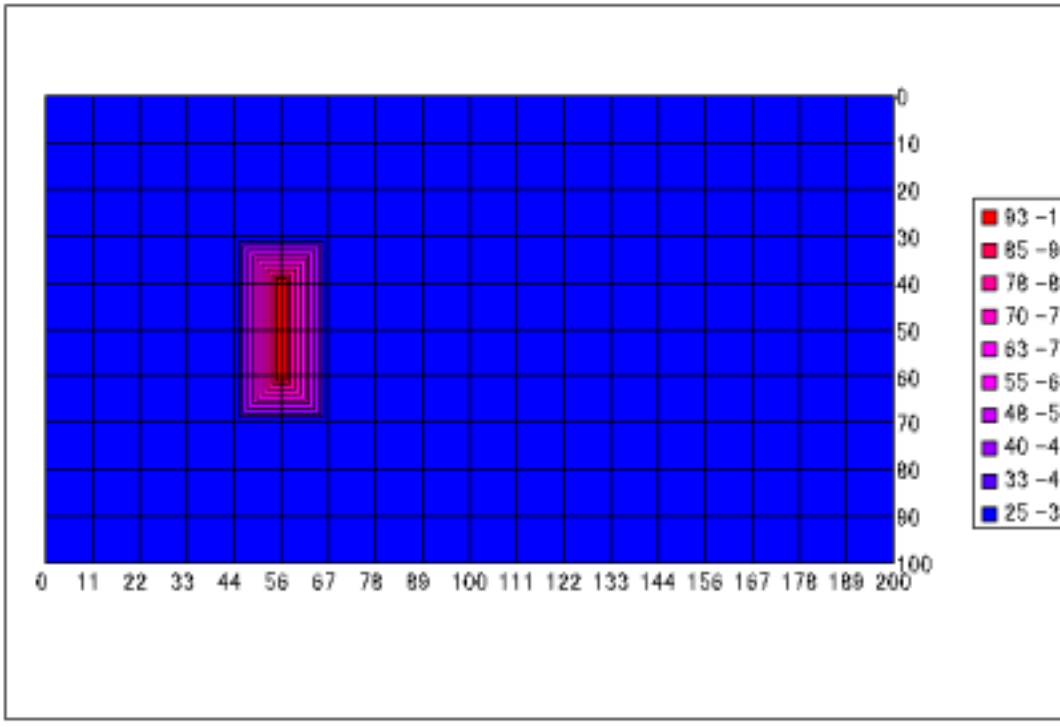
Students are young engineers in industries.

They do exercise with their own note PC.

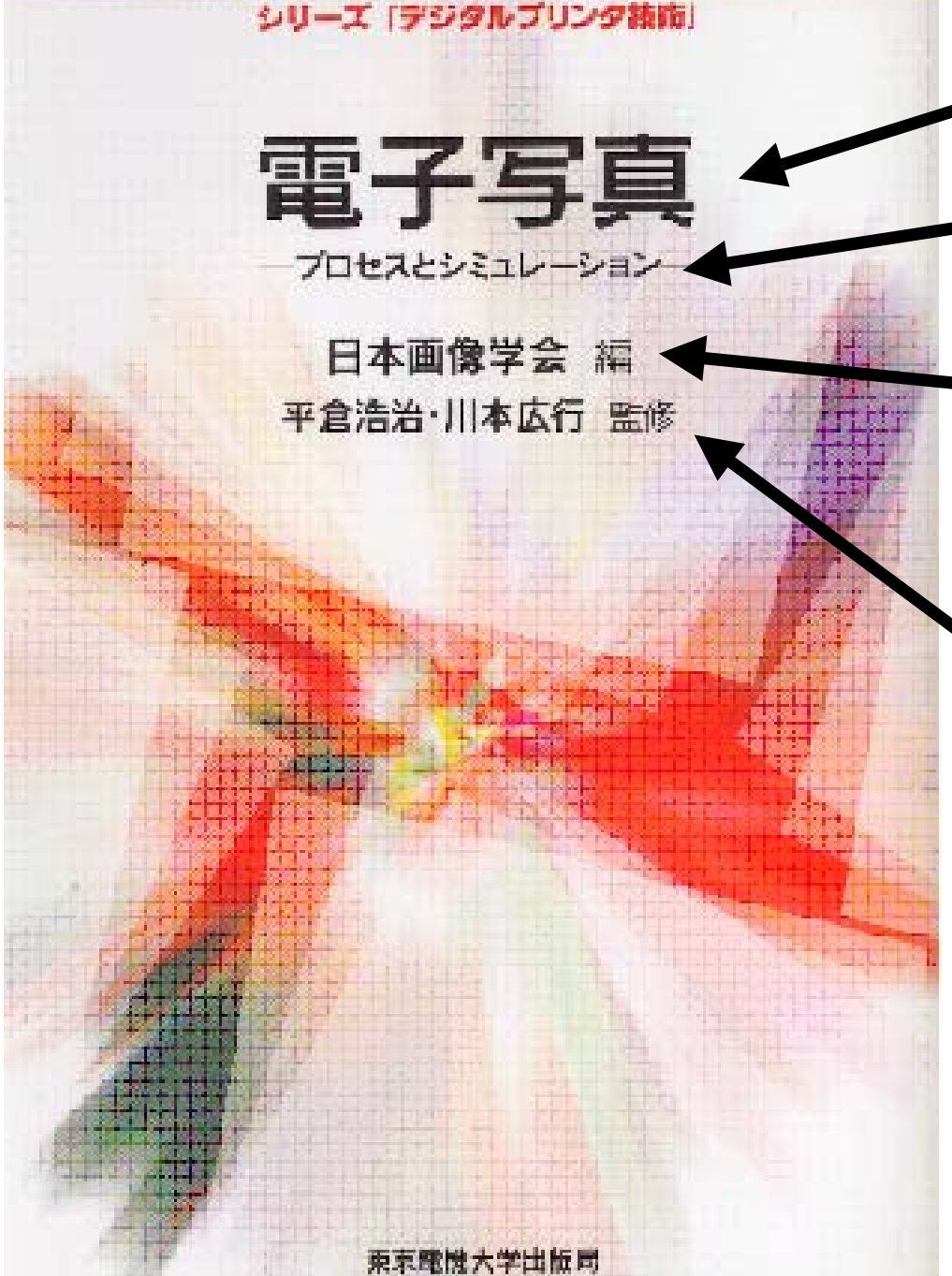
Example of Exercise

(Thermal Analysis of Belt Nip Fuser)





Students must complete the calculation at the end of one-day lecture !!



Electrophotography

Process & Simulation

Published by The Imaging Society of Japan

Edited by Hirakura (Ricoh) & Kawamoto

Textbook

Concluding Remarks

Simulation technology has been developed and widely utilized for the development of electrophotography machines,

although it had been believed that the simulation is ineffective for the electrophotography.

The electrophotography processes are no longer a black box.

Acknowledgement

I would like to express my sincere gratitude to my colleagues:

Dr. M. Kadonaga (Ricoh)
Dr. Y. Watanabe (Ricoh)
Mr. O. Takehira (Ricoh)
Dr. N. Kuribayashi (Ricoh Printing)
Dr. N. Nakayama (Fuji Xerox)
Dr. M. Kasama (Fuji Xerox)
Dr. T. Ito (Fuji Xerox)
Mr. H. Okamoto (Fuji Xerox)
Mr. M. Nakano (Canon)
Dr. H. Mio (Kyoto Fine Particle Technology)

for their beneficial suggestions and discussions.

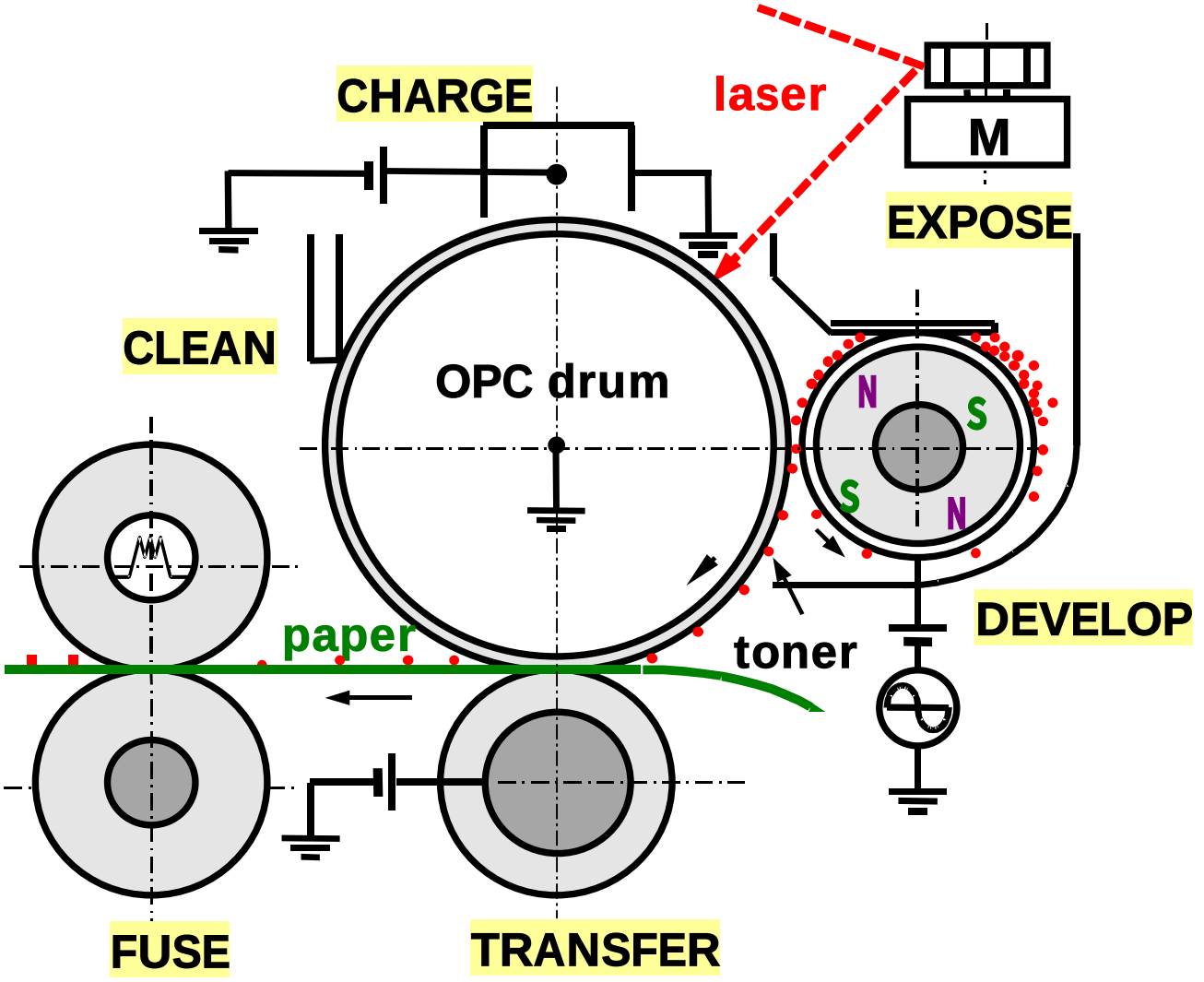
Thank you for your attention.

For more information

Hiroyuki Kawamoto, Prof.
Waseda University
Shinjuku, Tokyo
Phone/FAX: +81-3-5286-3914
E-mail: kawa@waseda.jp
http://www.kawamoto.mech.waseda.ac.jp/kawa/

end

Electrophotograpy Processes



History of Electrophotography Technology