Review of Electrohydrodynamics in Corona Devices in Electrophotography

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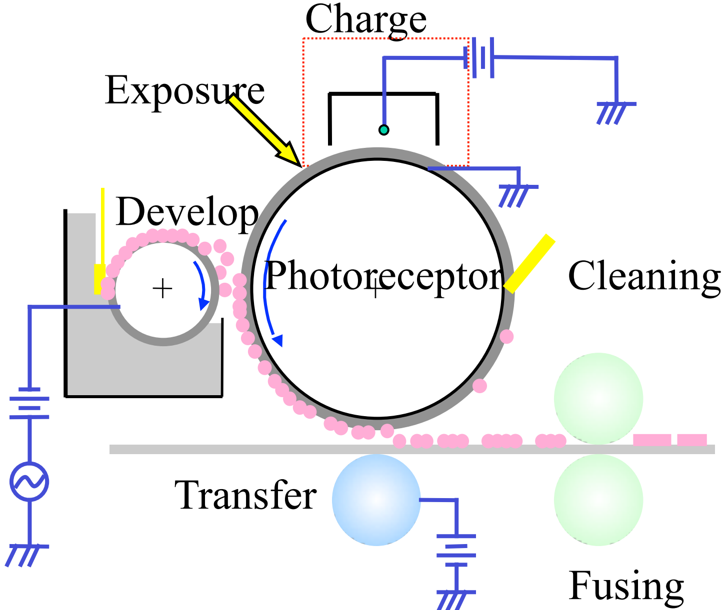
Fujifilm GSW690 & Velvia 50,
Agfa Ultra Color 100 of DxO FilmPack

1. Introduction

Corona discharge is applied to charging processes in electrophotography. **Corona discharge is surely a classic technology.** However, **corona devices are still used in high-speed machines.** On corona discharge, ionic wind occurs by the Coulomb force exerted on ions and collisions of ions and neutral molecules of gas. Ions collide with the molecules of the air, and transport the momentum to the air. The ionic wind transports oxidation products and so on, which cause image degradation and environmental problems.

Many investigations of corona discharge including the ionic wind have been conducted. In 2013, a paper using OpenFOAM was published. So we review of electrohydrodyanamics simulations in corona devices in electrophotography using computational fluid dynamics.



Electrophotographic process.

2.1. Charging Process in Electrophotography

Charging Process

Corona devices are used for charging the photoconductor, transferring toner to paper, neutralizing paper charges, and restoring the photoconductor prior to recharging it for another process cycle. In electrophotographic process, the charging current must be uniform across the width of the photoconductor or paper. A corotron, one of the corona devices, was invented to solve the problems encountered with bare corona wires and nonuniform charging. The corotron is a corona wire having an auxiliary electrode either above or around the wire to define the electrostatic field geometry and potentials in a controlled manner. The corotron can have infinite variety. The wire is usually at very high potential (～6 kV) and the auxiliary at very low (or ground) potential. A scrotron is a corotron with a biased control grid inserted between the wire and photoconductor. This configuration is possible to provide highly uniform charging and prevent overcharging. Corona charging can be used to apply either positive or negative charges to the photoconductor. The polarity of charging depends on the characteristics of the photoconductor.

We can numerically predict exit voltage on photoreceptor by simulating electric field in the corona device.

2.2. Equations for Unipolar Electrostatic Problem

F3,4)

Gauss' law

$$\frac{\partial(\varepsilon_{ij}E_j)}{\partial x_i} = \rho_e,$$

Charge conservation

$$\frac{\partial \rho_e}{\partial t} + \frac{\partial(\mu_e \rho_e E_j)}{\partial x_j} = 0, \qquad E_i = -\frac{\partial \phi}{\partial x_i},$$

⇩

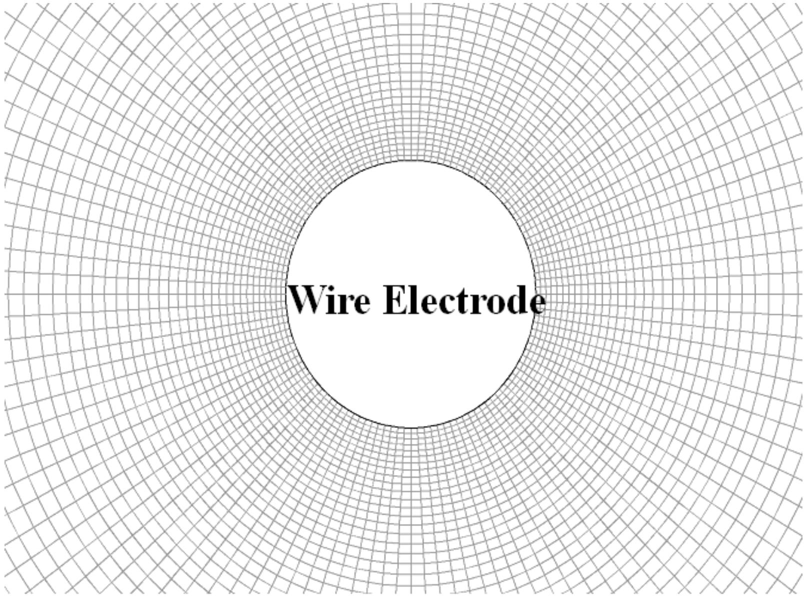
Mass conservation

$$\frac{\partial \rho}{\partial t} + \frac{\partial(\rho u_j)}{\partial x_j} = 0,$$

Momentum conservation

$$\frac{\partial(\rho u_i)}{\partial t} + \frac{\partial(\rho u_i u_j)}{\partial x_j} = -\frac{\partial p}{\partial x_i} + \frac{\partial}{\partial x_j}(\mu \frac{\partial u_i}{\partial x_j}) + \rho_e E_i.$$

2.3. Boundary Condition on the Wire



Mesh around the wire.

$F^{3,4)}$

Summation around the wire.

$$j = \mu_e \sum \rho_e E_i \Delta S_i, [A/m]$$

Charge density on the wire.

$$\rho_{e,new} = \rho_{e,old} + \alpha(E - E_0),$$
$$E_0 : Onset\_electricfieldstrength.$$

Electric potential on the wire.

$$\phi_{e,new} \Leftarrow Current\_j = const.$$

■ A user must input current density.

■ Both conditions on the wire are automatically defined in steady state.

2.4. Boundary Condition on the Wire

X[8)]

Charge density on the wire.

$$q_{wire}^{new} = (1-\alpha) q_{wire}^{old} + \alpha q_{wire}^{*},$$

$$q_{wire}^{*} = q_{wire}^{old} \left(\frac{\vec{n} \bullet \nabla V}{E_{onset}} \right)^{p}.$$

Electric potential on the wire.

$$\phi \,|_{wire} = const.$$

B[14)]

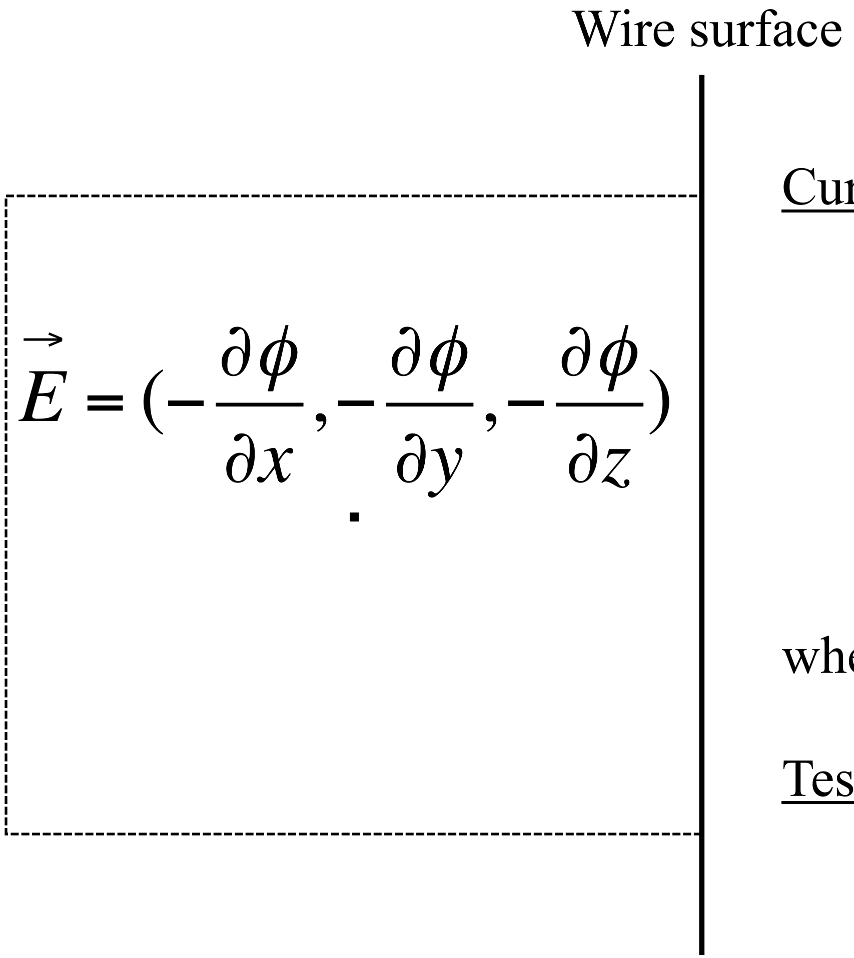
Charge density on the wire.

$$\rho(\varphi)\,|_{wire} = \rho^{(0)} + \sum_{m=1}^{n} \rho_a^{(m)} \cos(m\varphi) + \rho_b^{(m)} \sin(m\varphi).$$

Electric potential on the wire.

$$\phi \,|_{wire}^{i+1} = \phi \,|_{wire}^{i} + \beta \left(1 - \frac{2\pi k a \rho_i^{(0)} E_0}{I_0}\right).$$

2.5. Corona Discharge near the Wire



$$\vec{E} = \left(-\frac{\partial \phi}{\partial x}, -\frac{\partial \phi}{\partial y}, -\frac{\partial \phi}{\partial z}\right)$$

Current density on the wire

$$\rho_{e,new} = \rho_{e,old} + \alpha(E - E_0),$$

$$E_0 = 3 \times 10^6 \left(1 + 0.03\sqrt{\frac{1}{a}}\right),$$

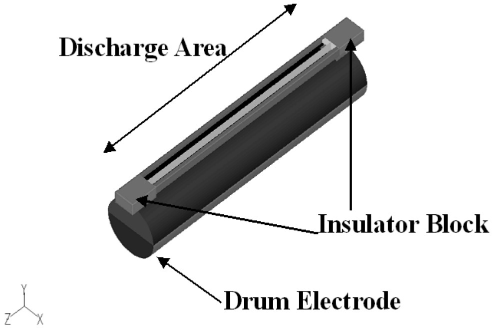
where a is radius of the wire.

Test parameters

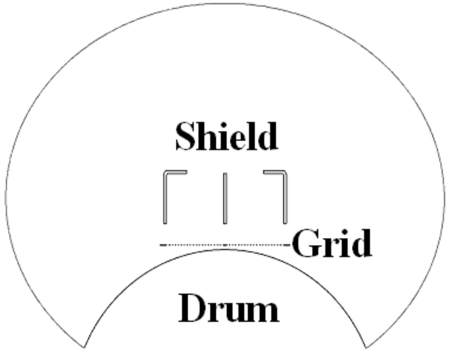
$$\alpha = 10^{-9}, E_0 = 10^7.$$

3.1. Example of Scorotron

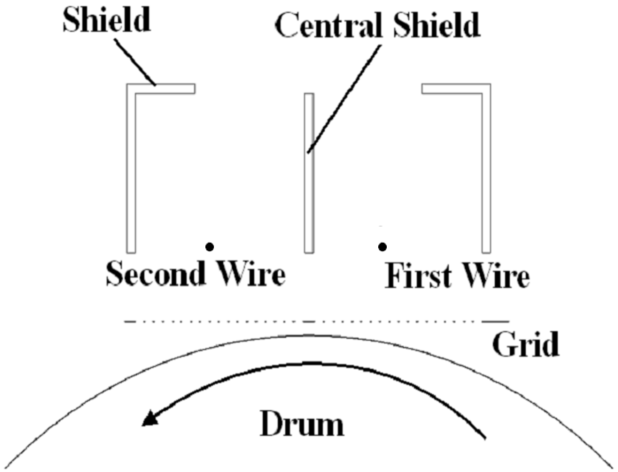
F[3,4)]



Scorotron and photoreceptor.



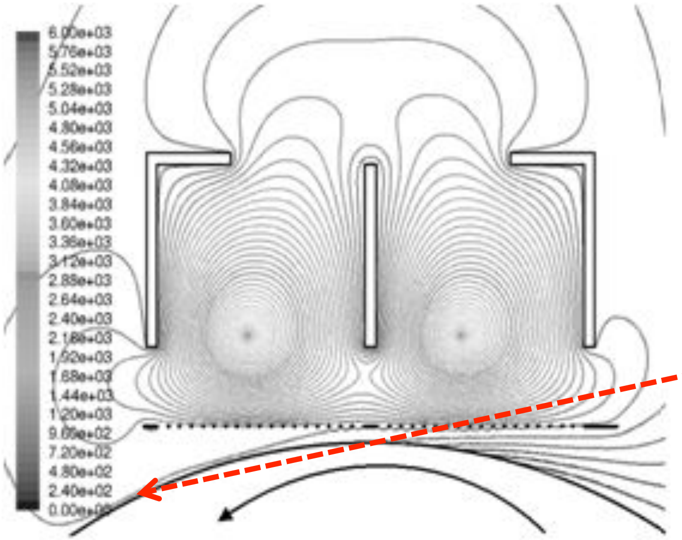
Two-dimensional analysis model of the double-wire scorotron.



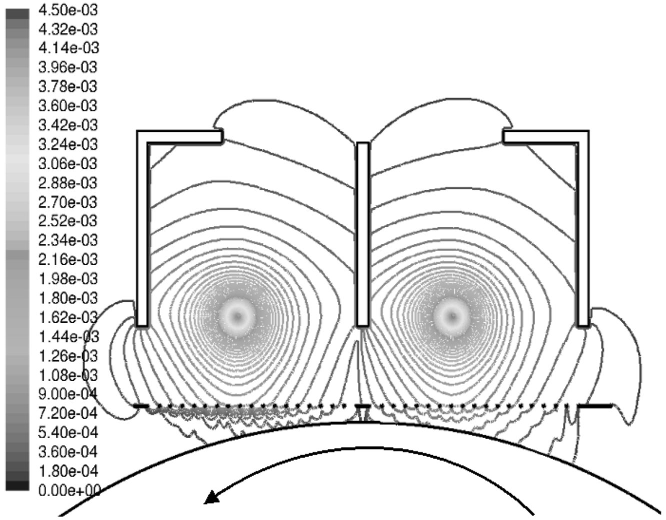
Cross section diagram of the double-wire scorotron.

3.2. Example of Electric Field

F3,4)

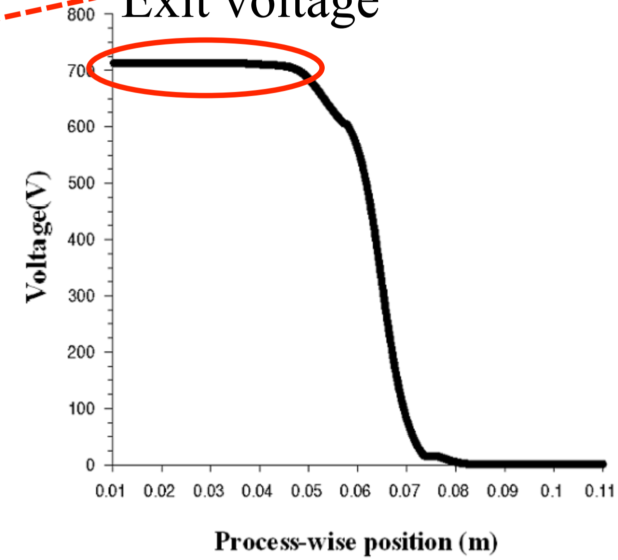


2-D static electric potential.



2-D charge density.

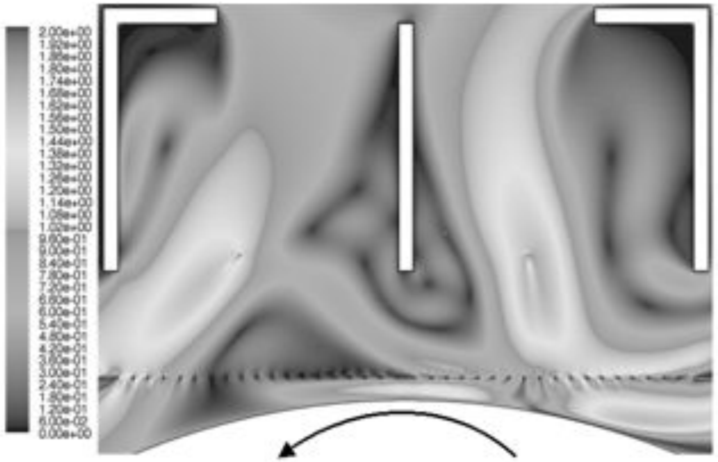
Exit voltage



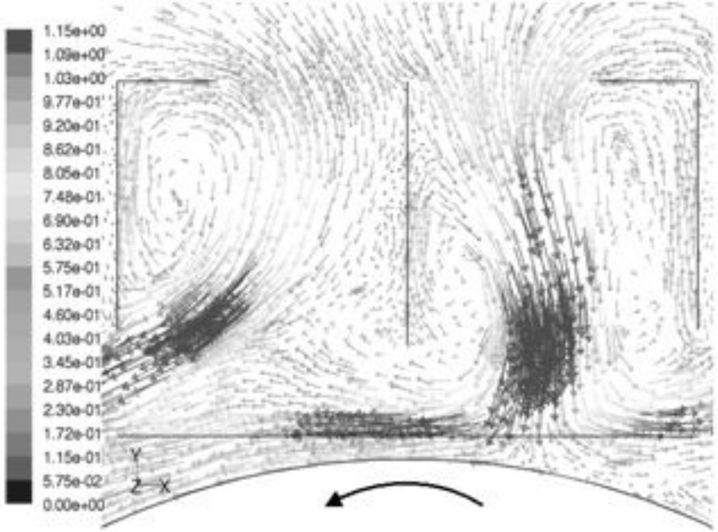
Static electric potential on the surface of photoreceptor.

3.3. Example of Ionic Wind

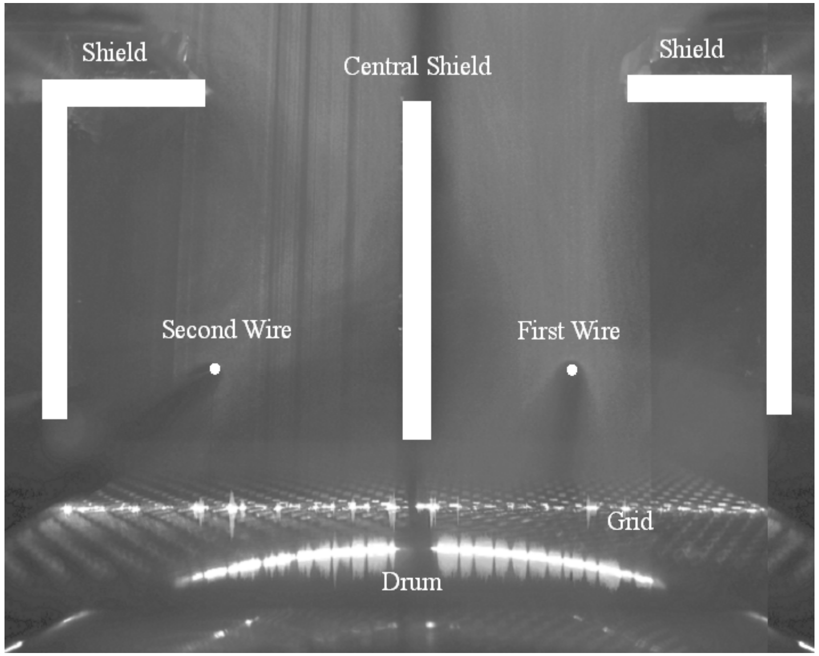
F[3,4]



Calculated 2-D contours of velocity magnitude on corona discharge.



Calculated 3-D velocity vectors on corona discharge.



Primary flow shown by smoke particles in the double-wire scorotron.

4. Summary of Electric Field Calculations

	X[8] (2006)	F[3,4] (2010)	B[14] (2013)
Used CFD Application	FIDAP US	FLUENT UDF	OpenFOAM
Corona dischrge on wire	○	○	?
Potential on wire [V]	Fixed(4500&6000)	Current	Current ?
Total current [mA/m]	0.197～1.096	-3.0～-9.0	0.375～1.5
Process speed [m/s]	0.25, 0.5	0.4～1.6	0.075～0.375
Radius of wire [m]	?	2×10^{-5}	3×10^{-5}
Width of corona device [m]	2×10^{-2}	3×10^{-2}	?
Height of corona device [m]	1.5×10^{-2}	2×10^{-2}	?
Radius of photoreceptor [m]	(Plate)	4×10^{-2}	1.5×10^{-2}
Error of exit voltage	3.3 %, -1,2 %	Max 3.7 % (12 cases)	?

- ■ A method using FLUENT is accurate for unipolar problems.
- ■ A method using OpenFOAM will be applied to bipolar problems.
- ■ **The electrical phenomenon around corona devices is physically simple.**

Ref 1. Papers of K. Mori

1) K. Mori, H. Okamoto and N. Hirooka, Computational Fluid Dynamics of Ionic Wind in a Corona Device in Electrophotography-(1), *J. Imaging Sci. Technol.* **48**, 465-472 (2004).
2) K. Mori, H. Okamoto, M. Shiraishi & A. Nishimura, Computational Fluid Dynamics of Ionic Wind in a Corona Device in Electrophotography-(2), *J. Imaging Sci. Technol.* **53**, 0405021-8 (2009).
3) K. Mori, Y. Nagamori, K. Otsuka, H. Okamoto & T. Ito, Unstructured Finite Volume Method of Electric Field in a Scorotron, *J. Imaging. Soc. Japan.* **49**, 2010, 248-254(In Japanese).
4) K. Mori, Behavior of Charged Particles around a Wire in a Scorotron on Negative Corona Discharge, *J. Imaging Sci. Technol.* **54**, 2010, 0605011-9.

Ref 2. Papers in Corona Devices in Elecrophotography

5) 渡辺好夫：電子写真用コロナ帯電器の放電シミュレーション，静電気学会誌，**14**，pp. 494-502（1990）.

6) 渡辺好夫，岡田健二，佐藤眞澄，行方伸一：コロナ放電デバイスの数値シミュレーション，電子写真学会誌，**30**，pp. 439-444（1991）.

7) H. Myochin, Y. Inoue and J. Okuno, Development of Corona Charger for the Reduction of the Bad Influence of Ozone on a Photoconductor, *Society J. Electrophotography*. **31**, 53(1992), (In Japanese).

8) P. Zamankhan, G. Ahmadi and F. Fan, Variation of Airflow and Electric Field in a Corona Device During Charging of a Moving Dielectric Substrate, *J. Imaging Sci. Technol.* **50**, pp. 375-385(2006).

9) 栗林夏城：数値解析モデルによる電子写真の印写プロセスの研究，北海道大学学位論文，（2006）.

Ref 3. Documents and Paper using OpenFOAM

10) M. K, 自己紹介(M. K)-OpenFOAMへの期待-, http://opencae.gifu-nct.ac.jp/pukiwiki/, 2011.

11) K. M., 静電ソルバーelctrostaticFoamとチュートリアルchargedWireの紹介, http://opencae.gifu-nct.ac.jp/pukiwiki/, 2011.

12) K. M, OpenFOAMを利用した電場−流体の連成ソルバー作成 elctrostaticFoam+icoFoam, http://opencae.gifu-nct.ac.jp/pukiwiki/, 2011.

13) M. Kobayashi, N. Uchida & H. Nogami, A Model for the Dynamics of Charging Photoreceptor and Ionic Wind in Positive DC Corona Discharge in Electrophotography, *Proceeding of NIP 28.*, 518-521.

14) M. Kobayashi, N. Uchida & H. Nogami, Numerical Simulations for the Design of the Positive DC Scorotron, *J. Imaging. Soc. Japan.* **52**, 2013, 495-500.