Ultra-slim developing unit design for continuous-feed production laser printers

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Abstract

The characteristics of continuous-feed production laser printers are wide-format continuous paper printing, very high print speed, and heavy-duty use.

These characteristics cause large machine size. In addition, large paper width requires large printer depth. To minimize the number of steps in the imaging process, a thin and wide developing unit is required. Furthermore, higher print coverage has recently become necessary. This, however, causes instability in toner concentration. It is therefore also important to maintain stability of toner concentration by correctly designing its control sequence.

To obtain uniform developer flow in very narrow spaces, analysis method has been developed. It is applied to the design in this study.

For obtaining smooth flow in slim (thin and wide)developing unit, combinations of two direction flows, which are quickly circulating developer in a cross section for a photoconductor movement and slower mixing with agree for its perpendicular direction, is needed. To achieve uniform developer flow rate and toner concentration in the imaging area, setting the optimum ratio of the two direction ratio flow rates is found to be an important factor. On the other hand, for obtaining stable toner concentration in a high coverage print, toner feed control is examined by using the analysis method. Employing PID control sequence attains sufficiently high stability.

A design concept for the ultra-slim developing unit is reported.

Introduction

Characteristics of continuous feed production laser printers are wide-format forms printing and very high print speed. These characteristics result in large machine sizes. Particularly, large paper width requires large printer depth. To minimize the imaging process unit size, a thin and wide developing unit design is required. In addition, recently, higher print coverage is needed for printing graphics images. A slim developing unit has thus been studied with this background in mind. One of problems with such a unit is imbalance of developer flow rate. It is necessary to make the developer flow stability. A stable flow rate makes a uniform distribution of toner concentration in the developer unit. Another problem is deviation of toner concentration.

In this study, a newly improved analysis method for developer flow and toner concentration, described in references[1–3], is used in optimizing developer flow with parts arrangement and toner-feeding control sequence. The key factors in designing a slim developing unit for continuous laser printers are revealed determined.

Ultra-slim developing unit

Construction of developing unit

Figure 1 shows a schematic of a developer unit for high-speed printers. This unit is for a two-component developing system, which uses a mixture of toner and carrier. The developer unit has three developing rollers A, B, and C, and one handling roller D. Roller A rotates counter to the direction of the photo-conductor feed. Rollers B and C rollers rotate with the direction. The developer is lifted up at roller D. It is then divided into three paths, which are set between rollers A and B. Developer in two of the three paths are fed to the development area. The other one is returned to the developer mixing area. When toner concentration is low, more toner is fed from toner hopper. And new toner is mixed with developer in the cross mixer, which is under roller A. The cross mixer has another function, that is, diffusing the developer in the direction of the paper width. It therefore produces a high-velocity developer stream in the magnetic direction and a slow flow in the paper-width direction.

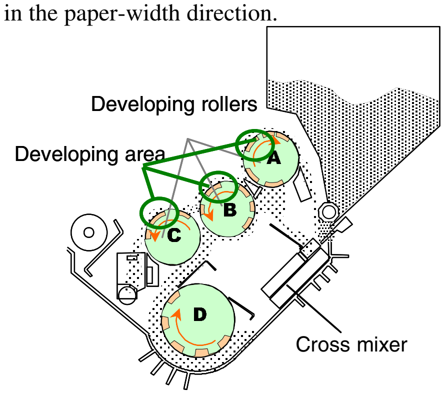

Figure 1*.Schematice of High speed Printer's developer unit*

Figure 2 shows a schematic of the present slim developer unit. The unit is made to meet two requirements. One is low developer volume and low height of unit. The other is high print coverage for graphics use. A rough specification for the slim developer unit are listed below for the base case model.

1. Print speed : 390mm/s to 890mm/s
2. Paper width : maximum 500mm
3. Developer : Two component developer type
4. Maximum print coverage : 30%

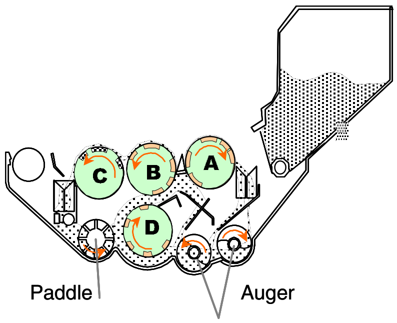

Figure 2. Schematic of slim developer unit

Problems and countermeasures for slim developer unit

Present approach is building concepts for the thin and wide developer unit. A basic problem for a slim design is a little assistance by gravity fall, which causes two further difficulties with design application. Furthermore, the design application difficulties are emphasized by the high-print-coverage requirement. One difficulty is obtaining sufficient developer mixing by the cross mixer, because the cross mixer needs a vertical height. A set of auger screws is therefore added to the developer unit to obtain sufficient mixing performance in the paper-width direction. It makes possible to apply for the higher print coverage. Another difficulty is a lack of horizontal path of the developer flow path that the developer flow path is not horizontal enough. One paddle is added to developer unit in order to obtain a horizontal drive force for handling the developer flow.

Analysis method

System model

Currently, DEM[4] and continuum fluid model[1-3] are used for analyzing powder flow. They can calculate powder flow with an almost real shape. However, it is difficult to calculate the whole developer flow in the developer unit. A system model with a one-dimensional geometry is therefore developed. This model is built for analyses of developer flow and toner concentration. It is used by up-winding finite difference method for calculating mass flow and toner concentration.

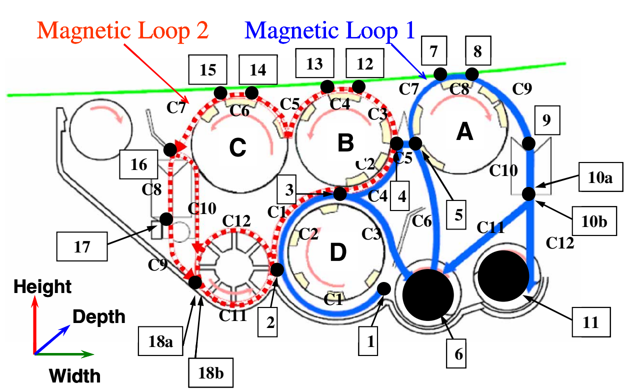

Figure 3. Flow path in the developer unit

Figure 3 shows a cross section of present developer unit with major flow path. The elements and conjunctions in the developer unit are shown in Figure 3. The flow paths are divided into several a few elements which are C1, C2…and C12. The properties of each element are diffusivity and toner consumption. Numbered points are conjunctions between the elements.

There are three major loops in the developer unit. Two loops are illustrated as continuous (Loop 1) or broken (Loop 2) lines in Figure 3. Figure 4 shows the one dimensional system model for the developer unit. The other loop (Loop3), which represents flow in auger screws, is in a cross section perpendicular to the other two loops, which represents flow in auger screws. Several sets of loops consisting of Loops 1 and 2 are connected to Loop 3. One of the sets is shown in Figure 4. Properties of each numbered point, which are separation ratio and toner mass exchanging rate, are obtained by measurement and 2D and 3D flow analyses.

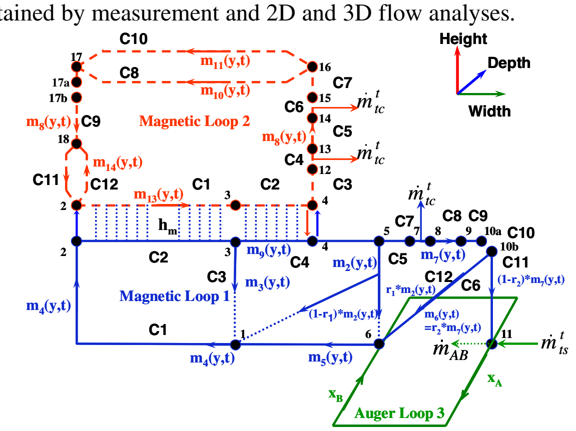

***Figure 4.**System model (block diagram)*

Equations (1) and (2) give developer and toner mass flow rates in Loops 1 and 2.

$$\frac{\partial m^d(y,t)}{\partial t}+\frac{\partial[u(y)\cdot m^d(y,t)]}{\partial y}-\dot{m}^d_{L1L2}=0 \qquad (1)$$

$$\frac{\partial m^t(y,t)}{\partial t}=-\frac{\partial[u(y)\cdot m^t(y,t)]}{\partial y}+\frac{\partial}{\partial y}\left[D\frac{\partial m^t(y,t)}{\partial y}\right]+\dot{m}^t_{tc}(y,t)+h_m(C_{L2}-C_{L1})+\dot{m}^t_{L1L2} \qquad (2)$$

In Equations (1) and (2), y is position at a certain depth, $m^d(y,t)$ is mass flow rate of develoer flow, (g/s-cm), $u(y)$ is develoer flow velocity, (cm/s), C_{L1} and C_{L2} are toner concentration, h_m is toner mass-transfer coefficient in toner exchange between Loop 1 (C1 and C4) and Loop 2 (C1 and C2), as shown in Figure 4, $\dot{m}^d_{L1L2}$ and $\dot{m}^t_{L1L2}$ are flow rate between Loop 1 and Loop 2 at point 4.

$$\frac{\partial m^t(x,t)}{\partial t}=-\frac{\partial[U(A)\cdot m^t(x,t)]}{\partial x}+\frac{\partial}{\partial x}\left[D\cdot\frac{\partial m^t(x,t)}{\partial x}\right]+\sum m^t_{in}(x,t)-\sum m^t_{out}(x,t) \qquad (4)$$

$$\frac{\partial m^d(x,t)}{\partial t}=-\frac{\partial[U(A)\cdot m^d(x,t)]}{\partial x}+\frac{\partial}{\partial x}\left[D\cdot\frac{\partial m^d(x,t)}{\partial x}\right]+\sum m^d_{in}(x,t)-\sum m^d_{out}(x,t)$$

$$A(x,t)=\frac{m^d(x,t)}{\rho} \qquad (3)$$

In Equations (3) and (4) are for deriving mass flow rate and toner concentration in Loop 3, x is position in depth direction, and

$m^d(x,t)$ and $m^t(x,t)$ are developer mass flow rate and toner mass flow rates. Suffix “in” denotes flow into Loop 3; suffix “out” denotes flow out of Loop 3.

A property at conjunction No. 1 in Figure 3 which major mass flow rate at roller D, is shown in Figure 5, for an example.

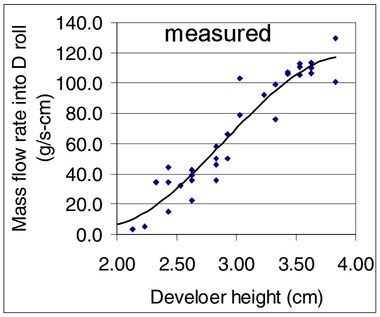

Figure 5.*Property curve at numbering point 1*

The other properties, namely, separation ratio at point 4 and toner diffusivity in the cross mixer at points 10a-10b and at points 17a-17b, are derived from measurements. The relationship between developer height and mass flow rate in auger Loop 3 is obtained from 3D FEM.

The toner concentration flow model includes a toner-concentration control algorithm. A toner-control program detects toner concentration from sensor point 17 in Figure 4. Toner is fed from all 11 Y points when toner concentration level is low.

Validations

The calculated results from the system model, which is assembled of several connected points and elements, are compared with measured results. The parameters used in the system model are adjusted in order to obtain agreement with the measured results. The comparison points for mass flow rate are m2, m3, and m4 in Figure 6. The comparison points for toner concentration are on the magnet rolls A and B in Figure 6.

The comparisons between the calculated and measured results are shown Figures 7 and 8. G/Gt represents mass flow rate. Whereas, G is mass flow rate and Gt is total mass flow rate averaged in depth direction. The total mass flow rate is equales to mass flow rate m4. Figure 8 shows toner concentration distribution on the A and B rollers in depth direction. Δ Ct($Ct-Ct_{,target}$) is the toner concentration difference from target which is defined in depth direction of the sensor position, point 17a in Figure 4. The measured and calculated results for the toner concentration slope with depth position agree well. The calculation accuracy of developer mass flow is within 20%. The accuracy of toner concentration is within 8%.

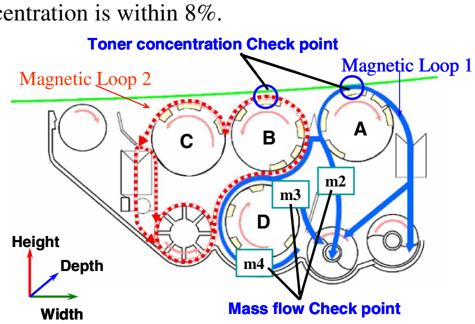

Figure 6.Check point *of mass flow rate*

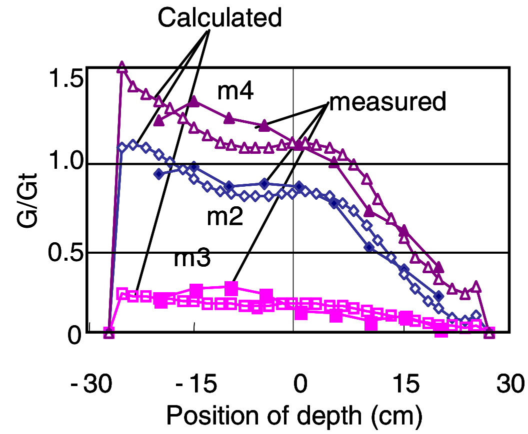

Figure7*. Calculation result of system model*

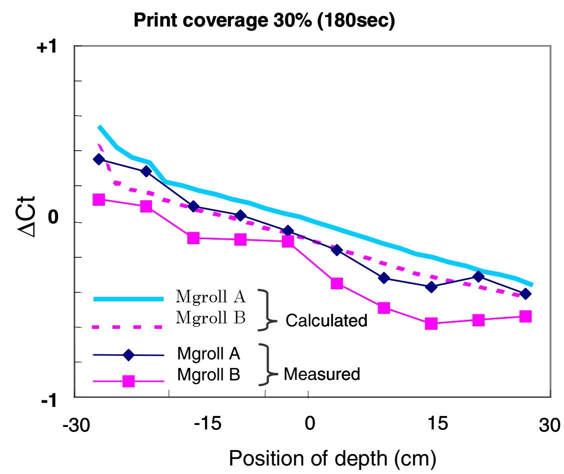

Figure 8. *Results of toner concentration analysis*

Analysis results

Principal factor for design

Currently, auger screws are widely employed in the developer unit for lower speed printers. Such a developing system with auger screws is designed so that the portion of auger screw that makes slow developer flow to depth direction for uniformity and developing roller flows that is fast flow to photo conductor movement direction, are separated. The two direction flows in each position are exchanged for a certain transfer ratio. The two direction flows in each position are exchanged for a certain transfer ratio. However, the proposed developer unit has an auger screw (Loop 3) that is protruded into the fast developer flow, which is in the direction of photo conductor movement (Loop 1). The relationship between flow paths and flow rate of magnetic loop 1 and auger loop 3 is therefore very important. Magnetic loop 1 and loop2 are arranged in parallel in the depth direction. The total mass flow rate of loop1 and loop 2 is defined at developer pick-up point 1 (m4) shown in Figure 9. It is important for the design. Mass flow rate m4 has a relationship with the free surface height of auger screw A. When the free surface height of the auger screw becomes lower level, the mass flow rate of point 1 (m4) is not enough. The lack of developer at loop 1 and loop 2 causes an irregular print image because of a lack of developer on the magnet roll at m4. Unevenness of developer mass flow rate in the depth direction causes non-uniformity of the printed image. m2 and m6 are separated into two flow paths, respectively. Moreover, r1 and r2 are defined as split ratio of m2 and m6, respectively. Auger A developer height is determined by r1 and r2. Figure 10 shows the relationship between split ratio r1 and mass flow which is defined from ratio and G/Gt which represents mass flow rate. σ is standard deviation of mass flow rate, which represents unevenness, with r1 is also shown in Figure 10. Figure 11 is concerning with r2 as shown in as Figure 10. Effective range of mass flow rate is shown in Figure 10 and 11. The G/Gt lower than target band causes lack of developer on developing rollers A, B, and C. The G/Gt higher than target band causes too much recirculated quantity of developer in Loop 1. It shortens the developer life.

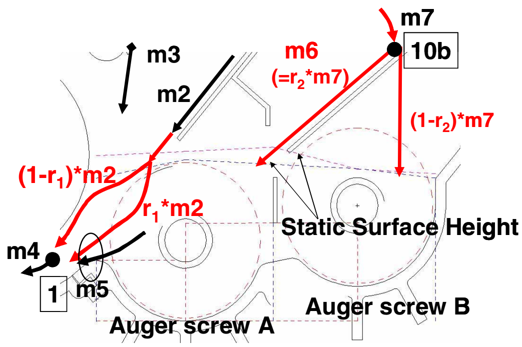

Figure 9. *Ratio of m2 going into auger A*

The following parameters change with split ratio:

- developer mass flow rate decreases with r1,
- mass flow unevenness increases a little with r1,
- developer mass flow rate and mass flow unevenness are minimized at r2=1.

Figure 12 shows the optimized developer mass flow rate calculated and measured in the depth direction.

For comparison with the optimized case shown in Figure 12, calculated results for r2 of 0.8 out of the range is shown in Figure 13. Compared with the results in Figure 13, the optimized result in Figure 12 looks uniform in the m4 distribution.

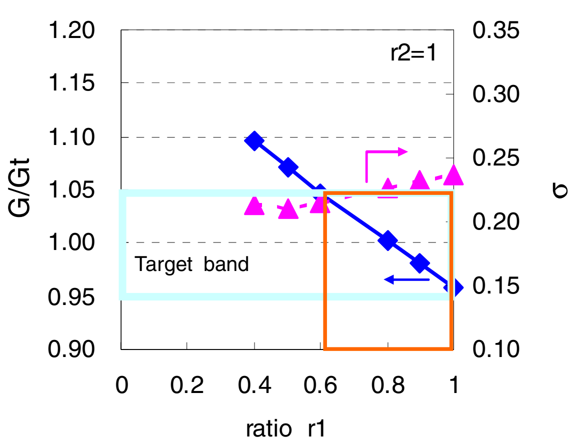

Figure 10. *Study of r1 vs. mass flow rate and Mass flow balance*

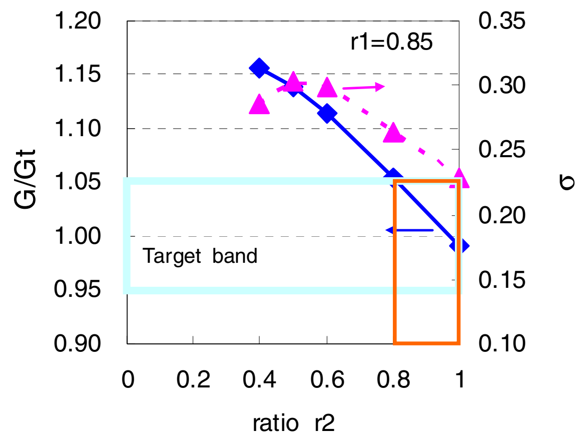

Figure 11. *Study of r2 vs. mass flow rate and Mass flow balance*

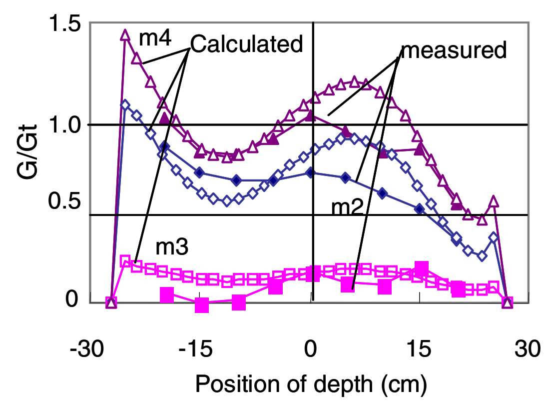

Figure 12. *Optimized mass flow rate*

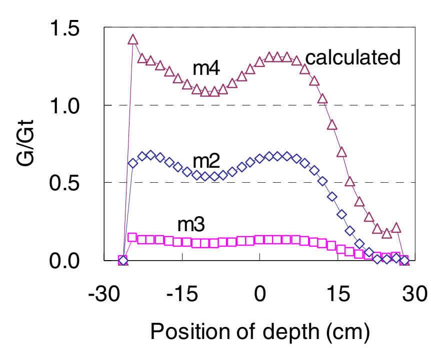

Figure 13. *Wrong mass flow rate*

Investigation of toner-feed control

The developed slim developer unit must meet two requirements, which are harmonizing flow and toner concentration stability. The former is mentioned above. Meeting the later obtains large print coverage without fluctuation. Fluctuation of toner concentration makes a non-uniform image among paper positions. This is caused by inaccurate toner feed control. The toner feed sequence of a current high-speed printer has a few problems providing high print coverage. The most serious problem is decrease in toner concentration with high-coverage printing. A new method of toner feed control is thus needed in order to obtain more accurate and flexible control.

Another advantage of the system model is capability for toner control algorithm study in computer. The objective of the control is keeping the toner-concentration uniformity on the developing rollers during printing. The problem with toner control is that there is time lag between sensing and feeding times. A large deviation of toner concentration sometimes occurs when the system has problems with geometry, sensor setting, and/or control sequence. Uniformity of toner concentration on the developing rollers in the depth direction is obtained by optimizing developer flow as mentioned above. The toner feed sequence is designed by using a 1D system model. This control sequence is then tested on the actual printer.

A proportional control sequence for toner feed is conventionally employed. In the conventional method, toner-concentration declination occurs in the case of high print coverage because feeding toner quantity is kept slightly low in order to avoid over shooting.

In this study, a PID control sequence is chosen for supporting high coverage print. Figure 14 shows a schematic of the control sequence, in which toner feeding concentration is judged from Equation (5). Here, a, b, c, and d are sensitivity parameters for PID control. When F exceeds zero, toner is fed from the toner hopper.

$$F = (P \times a) + (D \times b) - (I1 \times c) + (I2 \times d) \qquad (5)$$

Examined sensitivity parameters are selected by using the 1D system model. Figure 15 compares Δ Ct,Ct-$Ct_{,target}$ is derived flow toner concentration output, in the case of the conventional and proposed controls for the slim developer unit. It is clear that the proposed control scheme attains better stability for print coverage of 16% and 30% than the conventional scheme.

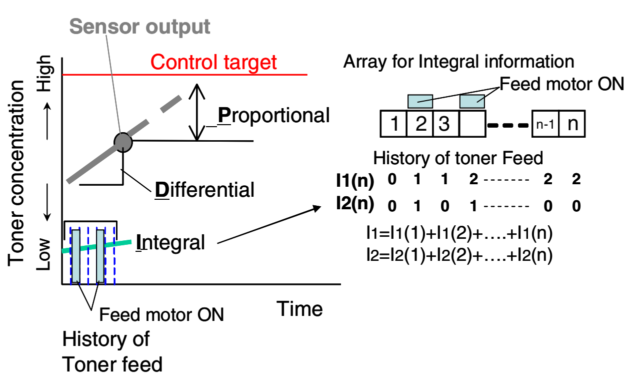

Figure 14. *Schematic of new toner feed control*

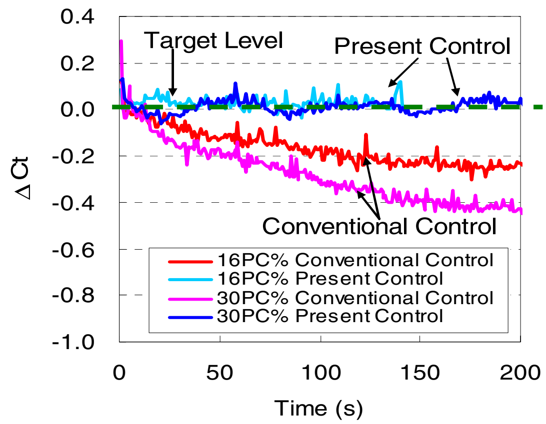

Figure 15. *Toner control test on the present slim printer*

Conclusion

The concept for designing the ultra-slim developer unit is examined with a conventional one dimensional system model. Design key parameters are obtained below.

1) The sprit ratio r1 and r2 are key parameters for obtaining ultra- slim developer unit.
2) Because of the slim geometry of the unit, a set of auger screws is required for better mixing performance in the depth direction.
3) For obtaining toner concentration stability in the ultra-slim developer unit, systemized control sequence, at least PID control, is needed.

References

[1] Y. Takuma et al.: NIP17 , p.606. (2001)
[2] Y. Takuma et al.: ICIS2 , p.594 (2002)
[3] Y. Takuma et al.: Japan Hardcopy2005 , p.239 (2005)
[4] P.A.Cundall et al.: Geotechnique, No.47. 29 (1979)

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Kaotu Kataoka received a B.E. degree in chemical engineering from Ibaraki University, Japan in 1986. He has developed laser-printer developing systems since 2004 in Hitachi-Koki.and Hitachi printing solutions. He is now engaged in computer analysis of developer flows in Ricoh Printing Systems,Ltd. He is a member of the Society of Powder Technology Japan and the Imaging Society of Japan.