Estimation of Temperature in Toner Fusing Field

Masahiro Samei, Takuo Shimokawa, Kazuki Takenouchi* and Kazuaki Kawakita*
Kyushu Matsushita Electric Co., Ltd., Fukuoka, JAPAN
***Kyushu Institute of Design, Fukuoka, JAPAN**

Abstract

A numerical approach is proposed to estimate temperature field in toner fusing process for improvement of fusers in electrophotographic printers. The outline of the numerical calculation is as follows: 1) Finite difference method is applied to discretize the equation of thermal conduction on the computed region consisting of a heat roller, air gap, toner, paper and a pressure roller. 2) The governing equation is solved by time marching with the alternating direction implicit method. 3) The rotation of the heat and the pressure rollers and the transfer of the paper are modeled by transfer of thermal properties, the procedure in which temperature and heat stored in a cell are transferred from the cell to the adjacent outgoing cell synchronizing with the rollers' rotation. 4) Toner fusing characteristics are modeled by using a constant melting point and a latent heat. The availability of the calculation is discussed compared with the temperature obtained in measurement, indicating the necessity of the introduction of an additional resistance in thermal conduction. The temperature distribution in the fusing region is also analyzed for obtaining fundamental feature of heat transfer.

Introduction

Lower energy consumption are always required for electrophotographic printers. Considering that more than 80 percent of electric power is generally consumed in toner fusing process, the improvement of thermal efficiency of fuser is therefore the most important.

Many printers adopting the system of heat roller fusing are major because of advantages in fusing quality and cost performance, but have some disadvantages such as higher power consumption and longer warming-up time. The heat roller fusing will be more attractive by the improvement of the thermal efficiency. It is necessary to obtain precise knowledge of the heat transfer phenomena in the fusing region for this improvement.

In this paper, a numerical method to estimate two-dimensional heat transfer phenomena in the fusing region will be proposed, and the effects of air involved in the fusing region on temperature distribution will be also discussed on the estimated results.

Outline of Toner Fusing Process

A schematic of heat roller fusing is illustrated in Fig.1. The fuser mainly consists of a heat roller and a pressure roller. The heat roller is composed of an aluminum core (1.5 mm in thickness) with a very thin fluoride resin coating layer (30 μm in thickness and 2−3 μmR_y in surface roughness) and heated on its inner surface by the radiant heat from a heater. The pressure roller is composed of an elastic rubber (6 mm in thickness and 1−3 μmR_y in surface roughness) with a stainless core. The two rollers are pressed against each other, and the deformation of the pressure roller then forms a fusing region in their interface. The toner fusing process is carried out during the residence in the nip in which toner is passed through the fusing region along with the paper. The heat stored in the heat roller is conducted to the toner particles due to their mutual contact, and brought out from the fusing region with the rotation of the rollers.

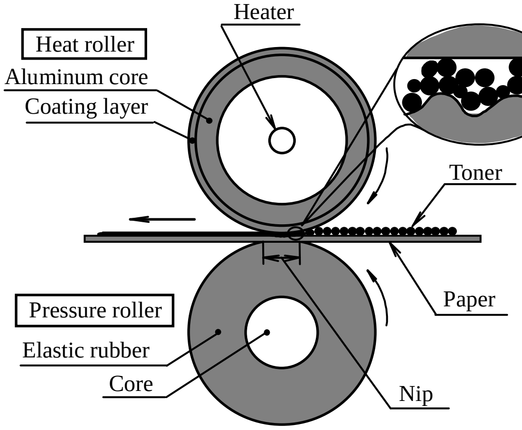

Figure 1. Schematic of heat roller fusing

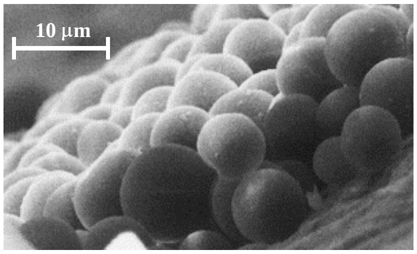

Figure 2. Toner particles deposited on paper

Figure 2 shows a SEM photomicrograph of the state of unfused toner particles deposited on the paper. The observation of the photomicrograph indicates that the diameter of toner particles is about 8 µm and they are deposited uniformly on the paper (100 µm in thickness and 10–15 µmRy in surface roughness), the deposition being considered as a layer with about 14 µm in thickness.

Technical Problems

For optimizing thermal efficiency of fuser, it is at first required to have quantitative knowledge of the heat transfer phenomena in the state of actual fusing condition. In analyzing the heat transfer experimentally, there are some difficulties in obtaining two-dimensional feature of the phenomena due to small dimension of fusing nip; numerical approaches are expected to be powerful alternatives for obtaining thermal characteristics in the region.

Some calculation models for the estimation of the temperature field in the fusing region have been reported[1,2]. In these reports, one-dimensional thermal calculation models were applied. Considering the effect of the heat flux caused actually by two-dimensional heat flow on the fusing field, two-dimensional thermal analysis for the region with the rotating field should be necessary to estimate the temperature in fusing field.

In constructing a numerical method, appropriate evaluation of thermal properties for heat conduction is one of the keys for precise estimation. From a microscopic point of view in Fig.2, it is considered that air existing in the fusing region should be taken into consideration due to porosity of the toner layer and surface roughness of the paper.

Since the thermal conduction of air is small compared to the ones of the toner and other members, this suggests that the thermal resistance of air has remarkable effects on the temperature field even if its quantity is small. The thermal properties of air included between members in the fusing region should be clarified and adequately modeled for the numerical method.

Numerical Approach

Concept of the Numerical Estimation

In the numerical method proposed here for estimating the temperature field in the fusing region, the below principles are adopted:

1) The method is available for the estimation of two-dimensional heat transfer phenomena.
2) The geometrical shape of the computed region is rectangle, because the order of the nip width is much smaller than the radius of actual heat roller curvature with deformation by nipping.
3) The effects of air contained in the region are considered in the form of an additional thermal resistance as an equivalent air gap layer.
4) The rotation of the heat and the pressure rollers can be taken into consideration in a simple way on a fixed computational mesh.

Governing Equation

The governing equation of the phenomena is the equation of thermal conduction in two-dimensional area:

$$\rho c\frac{\partial\theta}{\partial t}=\frac{\partial}{\partial x}\left(\lambda\frac{\partial\theta}{\partial x}\right)+\frac{\partial}{\partial y}\left(\lambda\frac{\partial\theta}{\partial y}\right) \tag{1}$$

where θ is the temperature, ρ is the density, c is the specific heat and λ is the thermal conductivity.

Equation (1) is solved under given initial and boundary conditions and then the temperature of the composed members in the fusing region are determined. The equation is discretized on the structural grid described in the next section and numerically solved by the alternating direction implicit (ADI) method[3].

Computed Region

The calculation model is illustrated in Fig.3. It is a two-dimensional thermal conduction model composed of six layers, the heat roller core layer, the heat roller coating layer, the thermally equivalent air gap layer, the toner layer, the paper layer and the pressure roller elastic layer, having the same width of the fusing nip, w. The letters x and y denote the directions of paper feeding and the layers' stacking, respectively. The thickness of each layer and the width of the nip are indicated in the figure. The equivalent air gap layer thickness δ_a is 5 µm as a trial; a further detailed discussion will be necessary. The area is divided into 500 by 7 µm interval in the x direction, and the layer thickness δ_h, δ_c, δ_a, δ_t, δ_p, δ_e is divided into 300, 8, 1, 4, 25, 25 elements at 5 µm, 3.8 µm, 5 µm, 3.5 µm, 4 µm, 4 µm intervals in the y direction, respectively.

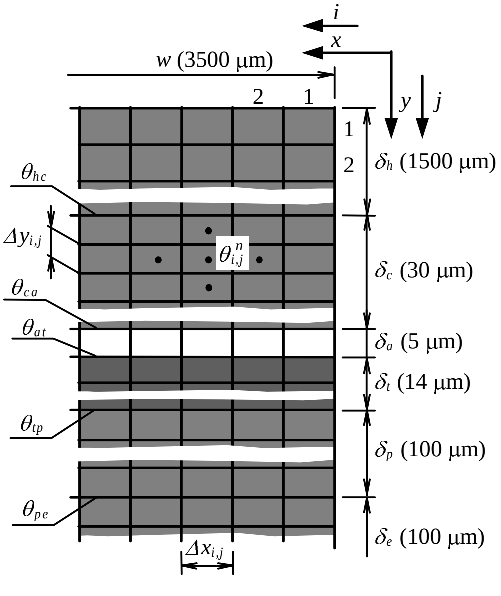

Figure 3. Computational mesh in the fusing region

Boundary Conditions

The constant heat flux q_h from the heater is supplied on the inner surface of the heat roller

$$y = 0 \ : \ -\lambda \frac{\partial \theta}{\partial y} = q_h \qquad (2)$$

and the adiabatic conditions are applied on the remaining three boundaries of the computed region.

In addition, the rotation of the two rollers is simulated by the transfer of thermal properties, the temperature and the heat stored in a cell, to the adjacent downward cell in the computed region synchronizing with the two rollers' rotation. The heat stored in the cell is brought out from the computed region at the outlet (x=3500 μm).

Phase Transfer Model of Toner

Toner is made mainly of styrene-acrylic or polyester resin. Due to the general characteristics of polymeric material, the toner does not have a distinct melting point. For the numerical application, the phase transfer process of toner is modeled by a constant melting point and a latent heat determined experimentally. The schematic explanation is illustrated in Fig.4.

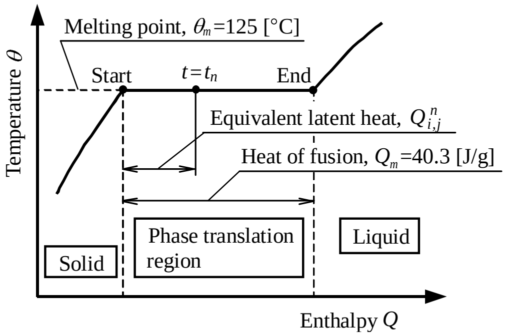

Figure 4. Phase transfer model of toner

Results and Discussion

Toner Layer Surface Temperature

The temperature change in the fusing region is estimated and shown in Fig.5. The properties of the members and operating conditions are listed in Table 1, 2 and Fig.4. The letter x and t denote the distance from the nip inlet and the residence time of the toner.

Table 1. Thermal Properties and Parameters in Calculation

Layer	δ [μm]	λ [W/(m·K)]	ρc [M J/(m^3·°C)]
Heat roller core	1500	228.6	2.50
Coating layer	30	0.181	1.64
Equivalent air gap	5	0.030	0.0012
Toner layer	14	0.151	1.51
Paper	100	0.080	1.16
Elastic layer	100	0.281	2.01

The results offer useful knowledge of the two-dimensional temperature field in the fusing region. The heat roller surface temperature θ_{ca} rapidly decreases to the minimum of 135°C at 0.24 mm behind the inlet (4 ms resident in the fusing nip) by thermal conduction to the toner and paper, followed by a moderate recovery with the temperature rise of the members. The toner–roller interface temperature θ_{at} reaches to its melting point θ_m at x=1.5 mm (t=25 ms) and the toner–paper interface one θ_{tp} at x=2.9 mm (t=49 ms). The complete phase transfer has been accomplished at x=3.2 mm (t=53 ms) through the phase transfer process in which the temperature θ_{tp} is kept at the melting point of 125°C. The toner layer surface temperature is 139°C at the outlet.

Table 2. Parameters in Calculation

Parameters	Values
Fusing speed, v	60 [mm/s]
Nip width, w	3500 [μm]
Heat flux from heater, q_h	31.9 [°C W/m^2]
Heat roller temperature, θ_h	180 [°C]
Environmental temperature, θ_s	25 [°C]

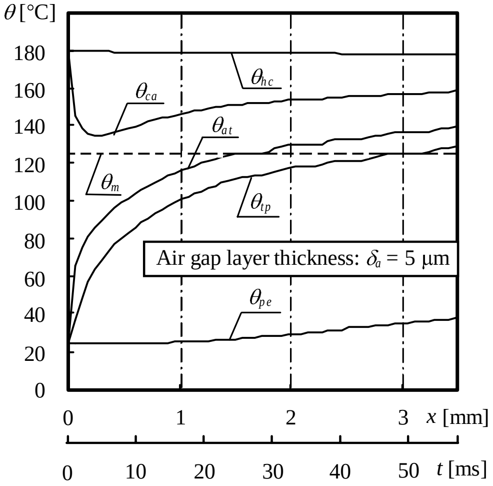

Figure 5. Estimated temperature change in the fusing region

For the discussion of calculated results by the numerical method, the temperature changes on the toner layer surface at the outlet of the fusing nip and the heat roller surface are measured simultaneously with an infrared radiation thermometer as shown in Fig.6 on 50×30 mm measured section at the center of the paper width. The resolution of the measurement is 0.52×0.52 mm in space and 0.6°C in temperature. The toner is deposited uniformly on the whole paper surface for the measurement.

The heat roller temperature at the inlet of the fusing nip is also measured by using a thermocouple in contact with its surface and controlled at 180°C in the room of temperature 25°C. The fusing speed is kept at 60 mm/s. The width of the fusing nip is measured by using a fiber-scope and set to 3.5 mm.

Shown in Fig.7 is one of the results. The toner layer surface temperature at the outlet of the fusing nip is measured 140°C. The good agreement between the measured temperature 140°C and the estimated one 139°C certifies the availability of the numerical estimation. Considering that an additional trial calculation with δ_a=0 μm gives the toner layer surface temperature 158°C at the outlet, the necessity of consideration of the equivalent air gap is also confirmed.

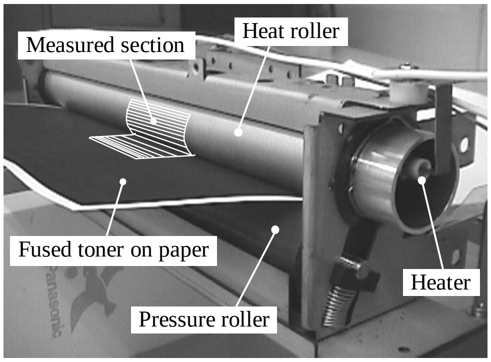

Figure 6. Temperature measurement by thermometer

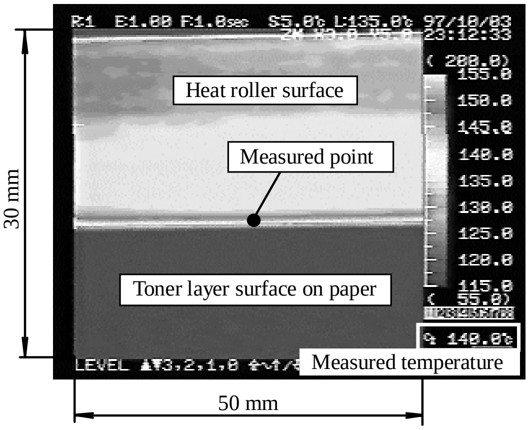

Figure 7. Temperature distribution at the outlet of the fusing nip

Temperature Distribution in Fusing Region

Figure 8 shows the calculated temperature distribution in the lateral direction in the fusing region taking *x* as a parameter.

From the figure it is clearly mentioned that rapid heat transfer occurs during the short period in the very beginning of the fusing process. With the progress of fusing, the temperature gradient in each layer decreases and become linear. In the toner layer, the temperature gradient is rather small compared with one in the other layers, there however is a significant temperature difference of 10.2°C between the upper and lower interfaces even at the outlet (*x*=3.5mm, *t*=58.3ms). Since the toner temperature strongly governs the final print qualities of fixing strength, glossiness and sharpness of image, the estimated results will offer important knowledge of the fuser performance. It is also clear that the temperature drop in the air gap layer is comparable to that in the toner layer in spite of its one third thickness of that of toner layer, pointing out the importance of air existence.

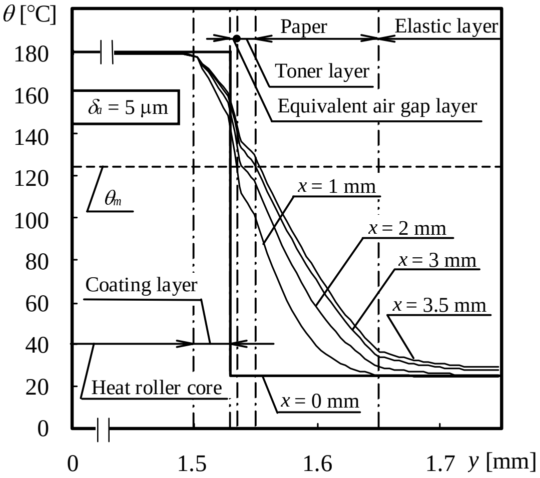

Figure 8. Estimated temperature distribution in the y direction

Conclusions

A numerical method for estimating the temperature field in the fusing region of electrophotographic printers is proposed and the estimated values are discussed. The results are summarized as follows:

1. A numerical approach based on ADI method is proposed considering the two-dimensionality of the heat transfer phenomena, the movement of the consisting members and the contained air in the region.
2. The estimated temperature on the toner layer surface at the outlet of the fusing region is compared with the one measured by infrared radiation thermometer. The agreement of the two values certifies the availability of the numerical estimation and the necessity of the additional thermal resistance by contained air.

References

1. T. Mitsuya, K. Masuda, Y. Hori, “Measurement of Temperature and Heat Flux Changes during the Fixing Process in Electrophotographic Machines”, *Trans. ASME. J. Eng. Ind.*, **118**, 150, (1996).
2. Y. Kuo, “Roll Fusing of Toner Particles on Rough Papers in the Xerographic Process”, *Polymer Eng. and Science*, **24**-9, 662, (1984).
3. D. W. Peaceman and H. H. Rachford Jr., “The Numerical Solutions to Parabolic and Elliptic Differential Equations”, *J. Soc. Ind. Appl. Math.*, **3**, 28, (1995).

Biography

Masahiro Samei received his B.E. and M.E. in Mechanical Engineering from Kyushu University, Fukuoka, Japan in 1987 and 1989, respectively. He has been working on Kyushu Matsushita Electric Co., Ltd., Fukuoka, Japan since 1989, where he is now a chief engineer. His current interest is in improvement of fuser performance.

E-mail address: samei@kk1g.kme.mei.co.jp