Heat Transfer Simulation for Thermal Design of Fusing System

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Abstract

For parameter design of xerographic process with simulation, suitable simulation models have to be established. Thermal control design of a complex fusing system requires a simulation tool not only with high accuracy but also with high speed. The simulation model developed in this study utilizes hybrid calculation technique of one and two dimensional heat transfer model and is capable of high speed calculation without losing accuracy. In this model, heat transfer efficiencies between components are defined and determined by one dimensional numerical analysis in prior. The simulation tool for belt roll fuser installed in Fuji Xerox Color 1000/800 Press was developed and applied to parameter design. As a result of the application, time required for the development was largely reduced.

Introduction

A fuser system fixes toner onto paper with heat and pressure in the xerographic process. Thermal control design of the fuser system is one of the most important matters for its development because too much or too small heat supply results in image defects, and non-uniformity of heat supply causes reduction in productivity. Therefore, uniformity of heat supply and temperature at nip region is an important subject to achieve high quality image and high speed printing. To achieve the uniformity in a limited development period, an accurate prediction of the relationship between control parameters and temperature in the nip region with a numerical simulation is effective for the parameter design of thermal control.

In order to determine parameters with a numerical simulation, a model which reproduces the heat transfer phenomenon of the whole fuser system has to be established. In addition, the model has to be able to produce the results with high-speed because parameters for the sequence control are evaluated by tracing the variation of temperature for long duration. Three dimensional models are desirable for accuracy but are time consuming in general. The efficient thermal network models [1] may be applied but they cannot produce important temperature distributions in each part. In this paper, a modeling technique for thermal parameter design is described. In the present model, the function expressing heat exchange between components in contact is defined with the heat transfer coefficients. The heat transfer coefficients are determined by one dimensional analysis in advance. Components of the fuser system are modeled by one or two dimensional models. With this technique, the model for belt roll fuser in Fuji Xerox Color 1000/800 press was built and applied to its parameter design.

Heat transfer phenomenon in a system

The heat transfer phenomenon around the nip region of a fuser system with a fuser belt is schematically shown in Fig 1. The heat generation from a fuser lamp in a heat roller Q_g, the heat storage in the system Q_s , and the heat dissipation to the surroundings Q_{out}, have a relationship expressed as the following equation:

$$Q_g = Q_s + Q_{out} \tag{1}$$

In this paper, a symbol Q with a subscript represents heat per unit time and has the unit watt. The heat conduction in a system is expressed by the unsteady heat equation [2] [3].

$$C_v \cdot \frac{\partial T}{\partial t} = \nabla(\lambda \cdot \nabla T - C_v \cdot v) + q_V \quad (2),$$

where C_v is the heat capacity, T is the temperature, q_v is the heat generation, v is the velocity, and λ is the heat conductivity of the target object.

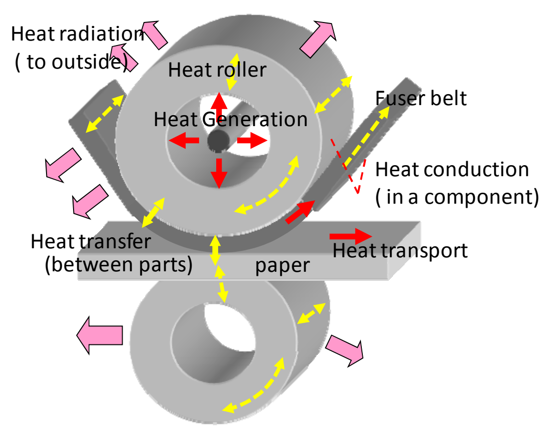

***Figure 1** Heat transfer phenomenon around nip region*

Heat transfer model of contact region

In the thermal control design, temperature of the fuser belt before the nip is the most important. Therefore, the relationship between the temperature before the nip and exchanged heat in the contact region is analyzed. A cross-section of a fuser belt and a roller rotating in the same velocity is shown in Fig.2. As shown in the figure, time before the contact t_0, just after the contact t_1, just before the detachment t_2, and just after the detachment t_3 are defined. The temperature distribution in the thickness direction of the belt and the roller is calculated with a one dimensional heat conduction analysis under the assumption that each part has a uniform temperature distribution at the time t_0 before contact. The temperature distribution along thickness direction during the contact from t_1 to t_2 is shown in Fig3 (a), and that after the contact from t_2 to t_3 is shown in Fig3 (b). These results show that, even though temperature gradient arises in the nip, the temperature becomes uniform again swiftly after the separation. Therefore, heat exchange between components can be characterized by the temperature before contact and that after the contact.

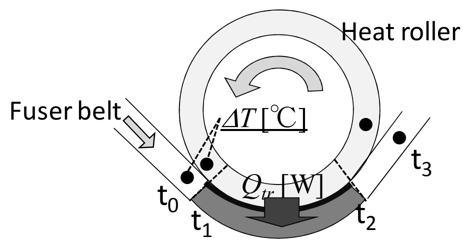

Figure 2 *Cross-section of contact region*

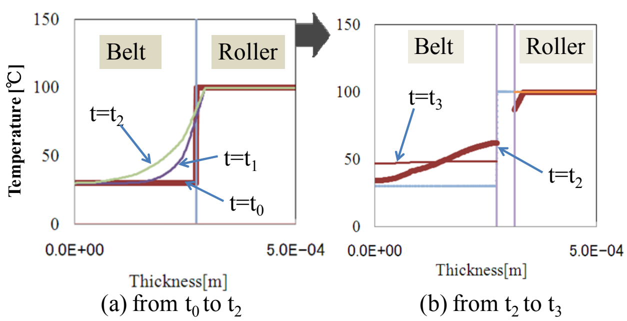

Figure 3 *Temperature distribution of thickness direction*

By similar analyses as the one described above with at different temperatures of the roller and the fuser belt, the relationship between the temperature difference before contact ΔT and transferred heat Q_{tr} is obtained as shown in Fig4. From the result, the transferred heat Q_{tr} is found to be almost linear with ΔT, and the slope of the line is defined as the heat transfer coefficient β.

$$Q_{tr} = \beta \cdot \Delta T \tag{3}$$

As the type of materials, the size of contact area, and the linear velocity are given, the coefficient β for each contact region is obtained by a thickness-wise one dimensional heat conduction simulation.

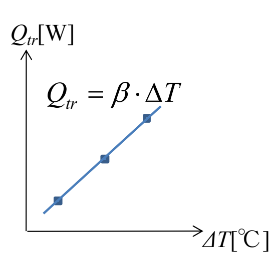

Figure 4 *Heat transfer model in contact region*

Fuser system model

A model of the overall system consists of one dimensional roller models, a two dimensional fuser belt model and the heat transfer model at the contact regions between them. In addition, the present model considers the heat dissipation at the surface boundary to the surroundings, and the heat transferred axially to the supporting components such as bearings. The heat dissipation Q_{out} and temperature of the surface and the surroundings has a relation as the following:

$$Q_{out} = Q_e + Q_{air} = \alpha(T_{ext} - T_{surf}), \tag{4}$$

where α is the heat transfer coefficient at the surface, T_{surf} is temperature of the surface of the components, and T_{ext} is that of the surroundings. Q_e is the heat which moves from the roller to the bearings at the both ends. Q_{air} is the heat which is released from the device surface to the air. The coefficient α is defined for each part and determined experimentally. An example model of the whole fuser system is shown as Fig.5. A roller is expressed as one dimensional model in the axial direction. T_{RA} represents the roller temperature just before contact with the fuser belt (point A), and T_{RB} represents that after contact (point B). The roller is divided into cells in an axial direction and the temperature distribution is obtained by solving discredited heat equation in every cell. The heat equation of point A is the following.

$$V_R C_{vR} \frac{dT_{RA}}{dt} = Q_s + Q_c + Q_{out}, \tag{5}$$

where Q_s is the heat generation from a lamp, Q_c is the heat conduction in a roller, and V_R is the volume of a calculation cell, C_{vR} is the heat capacity of the roll. The heat generation from the lamp Q_s is calculated considering the heat capacity of its own. A heat equation of point B is the following.

$$V_R C_{vR} \frac{T_{RB} - T_{RA}}{dt} = Q_{tr}, \tag{6}$$

$$Q_{tr} = \beta \cdot \Delta T = \beta(T_{BA} - T_{RA}), \tag{7}$$

where Q_{tr} is the heat transfer in contact area with a fuser belt, and V_R is the volume of the calculation cells, T_{BA} is the temperature of the belt just before contact.

The fuser belt is divided into cells in an axial and transportation direction. The two dimensional temperature distributions are obtained by solving the equation in the each cell. The relationship between the temperature of the belt before the contact T_{BA} and that after contact T_{BB} is expressed as,

$$V_B C_{vB} \frac{T_{BB} - T_{BA}}{dt} = -Q_{tr} = -\beta(T_{BA} - T_{RA}) \tag{8}$$

where V_B is the volume of the calculation cells, C_{vB} is the heat capacity of the fuser belt. In other cells (cells for non-contact region), the following equation is solved,

$$V_B C_{vB} \frac{dT_B}{dt} = Q_c + Q_{out} \tag{9}$$

where Q_c is the internal heat conduction. The heat transportation by the motion of the fuser belt is represented by moving cells to the rotation direction at every calculation steps.

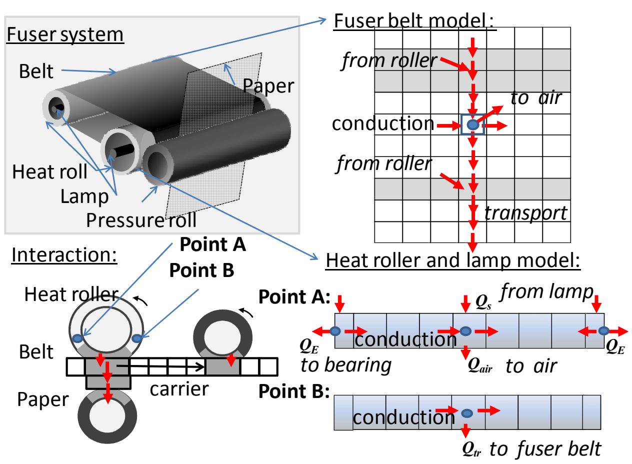

Figure5 *Heat transfer model of fuser system*

Application to parameter design

The simulation tool which was established with this modeling technique was applied to the design of thermal control parameters of BRF (Fig.6). BRF which stands for a "belt roll fuser" is a newly developed fusing technology [4]. The BRF technology realized high-speed and high-quality printing for a wide variety of paper, by maintaining the belt temperature with three rollers each having multiple heaters. Because of the complex configuration, the number of parameters for lamps and control sequences outnumbers that of conventional fuser system. Therefore the simulation tool utilizing the present model for the thermal control design of BRF was constructed to reduce the development period.

As one of the thermal control design, parameters for the warm-up mode were determined by the simulation tool. The warm-up-time is one of the most important matters, because it could affect the start-up time and the image quality of the first print. In the early phase of the development of BRF, the temperature uniformity after the end of warm-up mode did not meet the target level. Therefore, optimization of control parameters and lamps by the developed model are put into practice.

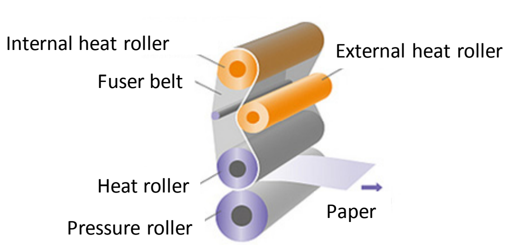

Figure 6 *Belt roll fuser in colo1000/800 press*

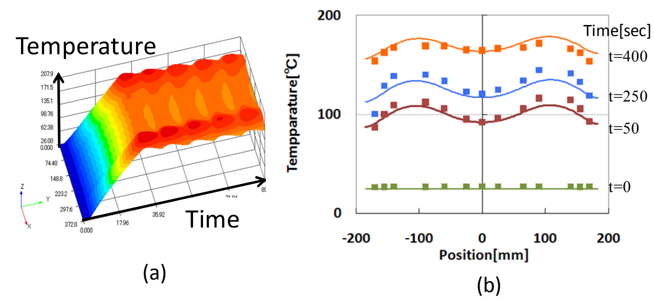

Figure 7 *Simulation result and measured temperature of warm-up time*

The temperature distribution predicted with the simulation tool is compared with the experimental data. The predicted temperature distribution of the fuser belt in the warm-up period is shown in Fig.7 (a). The comparison between the measured temperature and the calculated one is drawn in Fig7 (b). Symbols are the measured data, and lines represent simulated results. The difference between the measured data and the simulation results is less than 5°C. The accuracy of the tool was confirmed to be enough for the application to the parameters design.

Parameters were determined step by step. At the first step, an allocation of electric power for three rollers was determined. At the next step, distributions of lamps for warm-up period were optimized. At the last step, control sequences for three heat rollers were evaluated. As an example, the results of calculations at the last step are shown in Fig.8. In the figure, the temperature difference representing the non-uniformity is plotted versus several control sequence sets indicated by parenthesized numbers. From these results, the best combination of control sequences for temperature uniformity of the fuser belt was selected. With the present results, the uniformity of the temperature of the fuser belt satisfied the target level. To get the above results, about 100 times calculations for warm-up period were required. It took only1.5 day for these studies with simulation. These parameters were adopted in products, and the temperature uniformity met the target level as shown in Fig9.

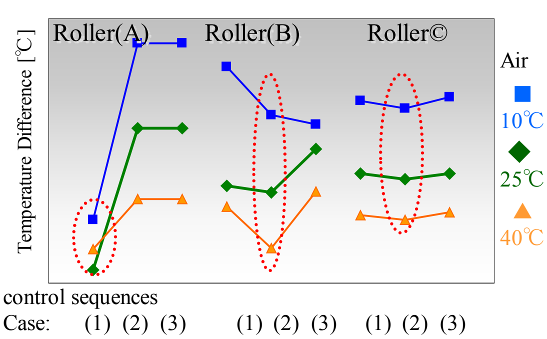

Figure8 *Results of parameter study for control sequences*

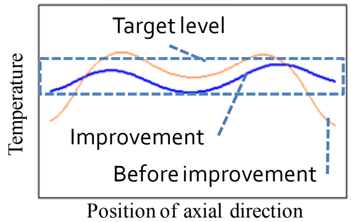

Figure9 *Improvement of temperature uniformity of fuser belt at the end of warm-up period*

Conclusions

Thermal control design is one of the most important matters for developing a fuser system. The improvement of temperature uniformity at nip region is principal subject to achieve high quality image and high speed printing. In order to determine parameters with a numerical simulation, a model which reproduces the heat transfer phenomenon of the whole fuser system with high-speed was established. In the present model, the function for heat transfer between components in contact is defined as the heat transfer coefficients. Coefficients for the heat transfer are determined by one dimensional analysis in advance. Each components of the fuser system are modeled by one or two dimensional models. With this technique, the model for a belt roll fuser in Fuji Xerox Color 1000/800 press was built and applied to its parameter design. The lamps and control sequences were optimized by the application of the present tool, and the time required for the development was largely reduced.

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Author Biography

Kitazawa,Kazuki received B.S. degrees in mathematics from Tsuda Univ. in 1993. She joined in Fuji Xerox.Co.,Ltd. and has been engaged in the research of electro photography. She mainly works on numerical simulation of electro photography system. She is a member of the Imaging Society of Japan, and the Quality Engineering Society.