Simulation Model to Predict Paper Wrinkle by Transportation Force Analysis

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Abstract

A simulation technology to predict a paper wrinkle in electorophotography printing process is developed. The paper wrinkle is a phenomenon that minute crease occurs on paper, and it is one of the major chronic troubles in electrophotography. To prevent the occurrence of the paper wrinkle, optimization of fusing parameters is necessary but enormous costs and hours are required for experimental approach. 3-dimetional dynamic structural simulations have been generally applied to predict the paper wrinkle, but they have not reached sufficiently practical level in terms of prediction accuracy, calculation stability and computational load. We established a simulation model based on a 2-dimentional static structural simulation in the plane perpendicular to axial direction. By using transportation force distribution exerted on paper in fusing nip as an evaluation index, prediction of the paper wrinkle occurrence rate became possible. The developed simulation technology was utilized for design of the radius difference rate of a fusing roller, and the optimum parameter was determined.

Introduction

A paper wrinkle is one of the chronic issues in electrophotography system. The paper wrinkle is a phenomenon that minute crease is formed on paper, and it occurs when paper is deformed into wavy shape as it is nipped by rollers and consequently folded in on itself. Meanwhile, an image disturbance caused by paper buckling is also one of the major issues and it occurs when a part of the fusing device scratches unfixed toner before fusing. The image disturbance has a paradoxical relationship to the paper wrinkle. These two chronic troubles are caused by inadequate axial distribution of transportation force exerted on paper in the fusing nip. Therefore, design of the fuser parameters to optimize the transportation behavior of paper in fusing nip is important to develop a reliable printing system. However, the transportation behavior of paper is a complex phenomenon that is affected by nonlinear dynamics of minute frictional slipping. Therefore, it has been difficult to predict effect of fuser parameters to the paper wrinkle and the image disturbance.

Recently, to satisfy the demand for high quality of printing and to reduce the cost of development simultaneously, simulation technologies are used to determine parameters of printing devices. As a typical simulation technology that deals with paper deformation, the model of paper curl prediction has been built by the authors [1, 2]. Meanwhile, 3-dimentional structural simulation to reproduce the paper wrinkle by Yanabe [3], and analytical model that evaluates wavy deformation of paper by Matsumoto [4] has been reported. However, a simulation technique that enables prediction of the paper wrinkle and the image disturbance caused by paper buckling at the same time has not been established. Therefore, parameter design to avoid the occurrence of them has been conducted experimentally, and enormous resources have been required in development process of every new product. One of the reasons why simulation technology to predict the paper wrinkle with practical accuracy has not built is instability of the calculation involving highly non-linear phenomena such as buckling and frictional minute slipping. In addition, calculation load is another obstacle, because computational grid to express the paper wrinkle deformation itself must be minute size. In this study, instead of calculating the deformation behavior of the paper wrinkle itself, the distribution of transportation force exerted on paper was evaluated. By using this method, the stability of simulation is secured because the calculation of non-linear phenomena can be avoided. In addition, usage of 2-dimentional static analysis to calculate transportation force distribution reduces the computational load drastically.

Control mechanism of the wrinkle

The wavy deformation of paper is caused by various factors such as non-uniform friction coefficient, contraction distribution of paper and so on. The paper wrinkle occurs when the wavy area of paper is nipped by fusing rollers or pads. Therefore, to avoid the paper wrinkle, it is important to correct the wavy shape before the nip by applying axial tension in the area before the nip. Generally the axial tension on paper is produced by distribution of transportation force in the fusing nip as shown in Figure 1. Figure 1 shows that the rotational moment generated by the transportation force distribution results in the tension in the axial direction in the area before the nip. The larger the transportation force variation is, the larger the tension occurs. Usually, the distribution of the transportation force is generated by a flared roller and controlled by its radius difference rate which is defined as the quotient between the roller radius at the end and that at the center. The

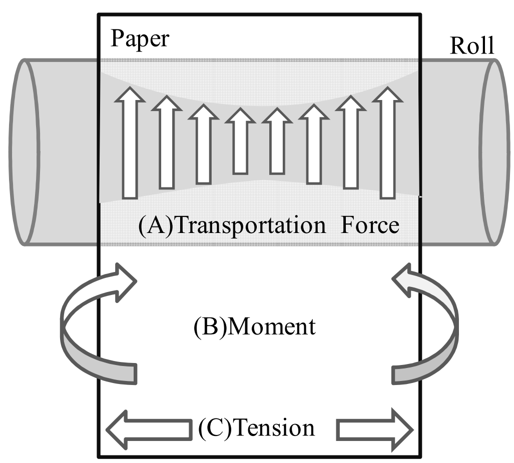


Figure1. *Mechanism of the paper winkle control*

transportation force variation and resulting axial tension increases as the radius difference rate becomes large. When the variation of the transportation force is not large enough, the axial tension to correct the wavy deformation of paper is insufficient and the paper wrinkle consequently occurs. On the other hand, the variation of transportation force is excessive, paper is buckled by the rotational moment and the image disturbance occurs. Therefore, to ensure reliability of a printing system, it is necessary to design the radius difference rate so that both of the paper wrinkle and the image disturbance are avoided. However, these two phenomena have high sensitivity to conditions other than the geometric parameters, such as temperature, paper brand and order of printing jobs. Enormous resources are required for optimization considering all combinations of factors, and that is why development of simulation technology to predict the paper wrinkle has been demanded.

Modeling

The calculation flow of the transportation force distribution exerted on paper is shown as Figure 2. To simplify the model, the rollers are divided by finite number of equally spaced imaginary planes perpendicular to the axis. The distributions of pressure and surface velocity are estimated for each plane by 2-dimensional static structural simulation considering the axial variations in radii of the fusing rollers. In the present study, a general purpose FEM simulator, Abaqus [5] was used for the 2-dimensional simulation. The frictional coefficient was measured by a friction table shown as Figure 3. The friction table is the device that is capable of quantifying frictional coefficient between two materials by contacting a block consisting of one material with rotating table consisting of the other material. In this study, the frictional coefficient was measured varying slipping velocity, temperature and pressure to obtain dependency on each of them. The temperature distribution at the nip area is calculated by heat transfer simulation using FDM. Given a position in the contact area, the absolute value of the transportation force is calculated as the product of the calculated pressure and the measured frictional coefficient, and its direction is determined by relative velocity between the paper and the fusing rollers. Finally, the entire distribution of transportation force exerted on paper is obtained by combining the distribution calculated for each plane through all the range in the axis direction. Since this method is based on static 2-dimensional calculations, the computational load can be reduced by one tenth or less compared with the 3-dimentional dynamic simulation.

As an example, a transportation force distribution of the fusing device consisting of hard roll and soft roll shown as Figure 4 was calculated. The calculation result of the pressure distribution is shown as Figure 5. The pressure exhibits arc-shaped distribution with the peak at the center position of nip area. Figure 6 is the calculation result of surface velocity distribution of surfaces of paper and both rollers. The result indicates that the velocity of the hard roll is constant across the entire nip area because the hard roll hardly deforms. On the other hand, the velocity of the soft roll varies because of in-plane deformation of the roller surface. The velocities of both paper surfaces are constant because they depend on paper thickness and bending curvature both of which are constant. The calculation result of the distribution of transportation force exerted on paper is shown as Figure 7. The result indicates that the force has positive value on side1 and negative value on side2. This result may be understood by observing Figure 6, in which the velocity of the

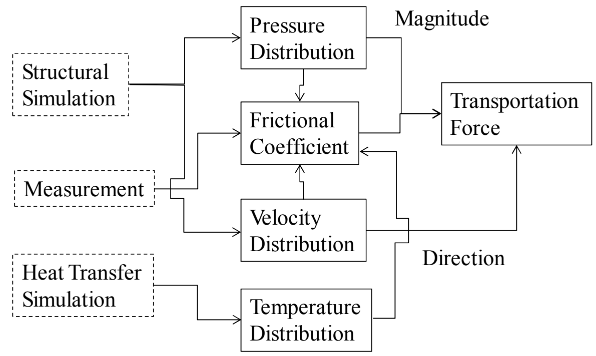


Figure 2. Analysis flow.

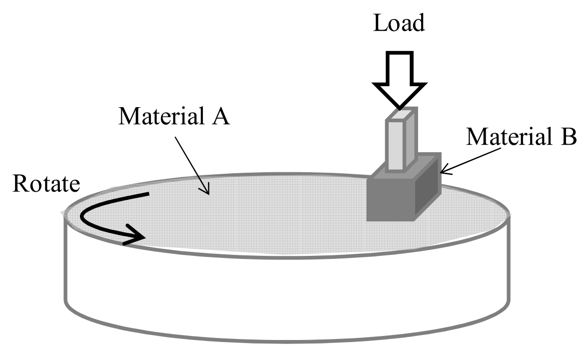


Figure 3. Friction table.

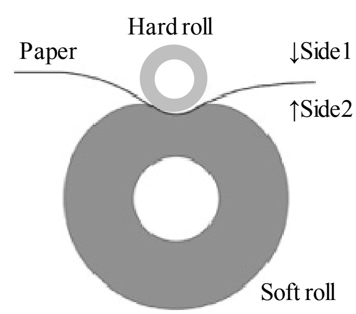


Figure 4. 2Roll fusing system.

hard roll is larger than that of side 1 of the paper, and soft roll is slower than side 2 of the paper. Paper is accelerated at the position where positive force is exerted, and it is decelerated when negative force is exerted. In the present research, to evaluate risk of the paper wrinkle and the image disturbance, an evaluation index is defined as an axial variation rate of the transportation force. When the evaluation index increases, the axial tension exerted on the area before the nip of paper increases also.

Result and discussion

The validation of the simulation model and application for fusing parameter design were conducted using Belt Roll Fuser

(BRF) system [6] shown as Figure 8. The BRF is the fusing system that is installed in high end production printers.

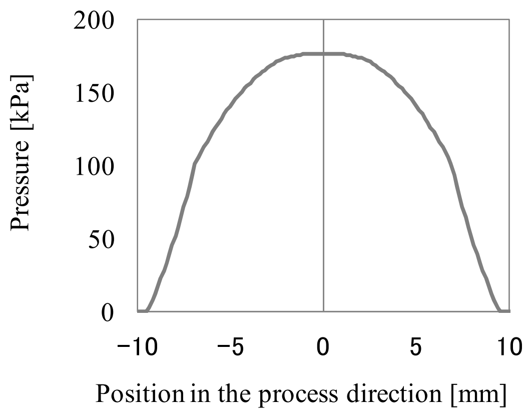


Figure 5. *Calculation result of pressure distribution.*

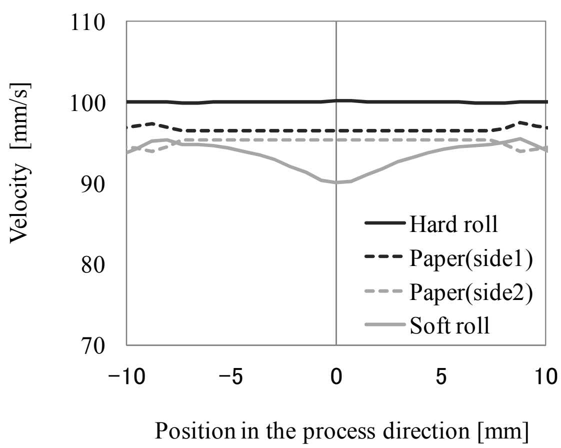


Figure 6. *Calculation result of Velocity distribution.*

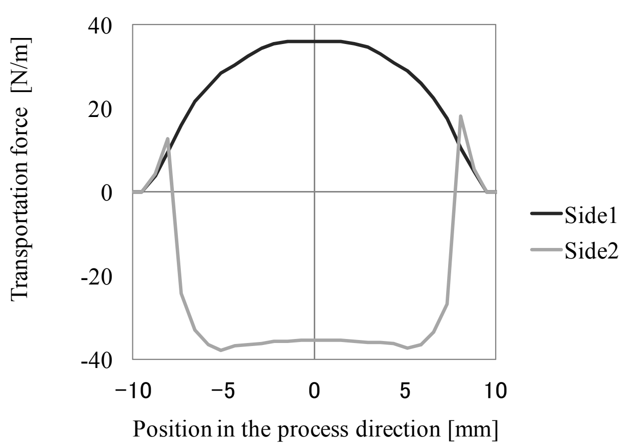


Figure 7. *Calculation result of Transportation force distribution*

For the validation of the model, experimentally measured occurrence rates of the paper wrinkle and the image disturbance were compared with the evaluation index calculated by the present model. The condition used for the validation is shown in Table 1. Here, the occurrence rate of each defect was controlled by changing the radius difference rate of the pressure roll. As the paper brand, thin coated paper, Topkote Plus, was chosen because of its high sensitivity to the defects of interest caused by its low rigidness and high frictional coefficient. The validation result of the paper wrinkle is shown in Figure 9 (a) and that of the image disturbance is shown in Figure 9 (b). These results indicate that occurrence rate of the paper wrinkle increases as the evaluation index became smaller. On the contrary, the image disturbance occurred more frequently when evaluation index became larger. From these result, it was confirmed that the evaluation index has good correlation with the occurrence rate of both defects. It was also clarified that there was the range of evaluation index within which neither defects occurred. Therefore, by designing the radius difference rate of the pressure roll so that its evaluation index falls within an adequate range, both defects can be avoided. The adequate range of the evaluation index varies depending on paper brand, and it depends on rigidness and frictional coefficient of paper.

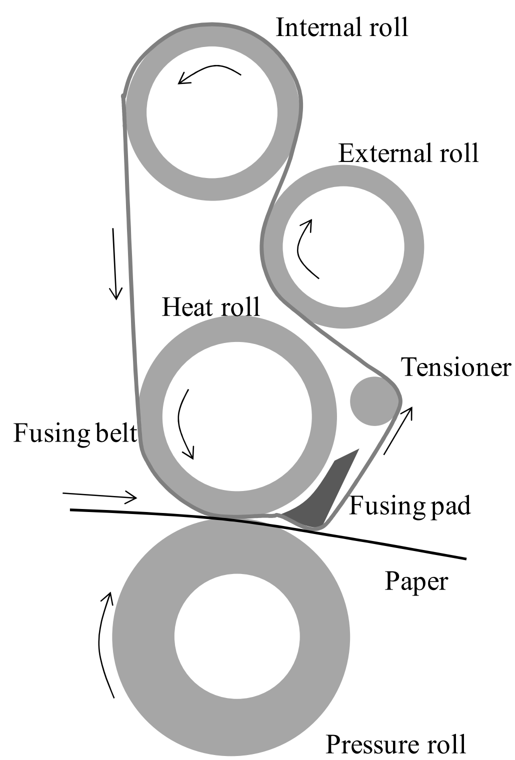
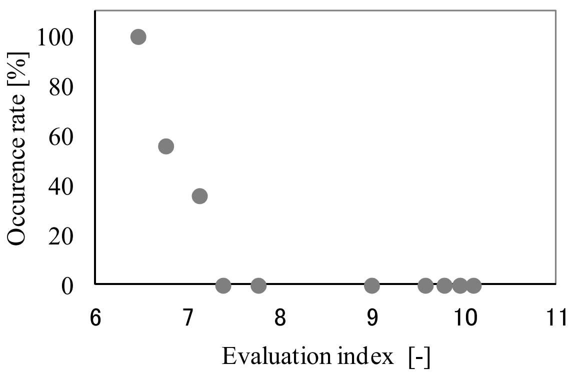


Figure 8. *Belt Roll Fuser system.*

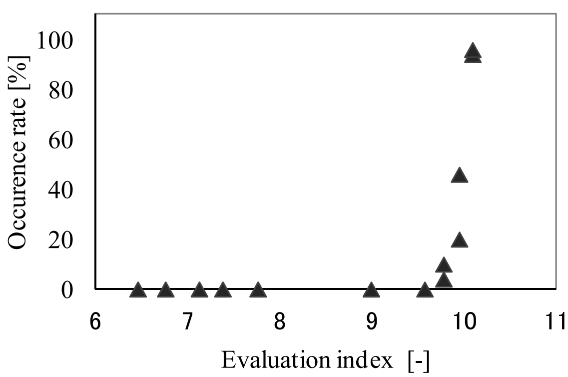
Table 1 Validation condition.

Factor	Parameter
Fusing system	Belt Roll Fuser
Radius difference rate[%]	0.0, 0.1, 0.2, 0.3
Paper brand	Topkote Plus

Basis weight[g/m2]	73.3
Number of sheets	50



(a) Paper wrinkle



(b) Image disturbance

Figure 9. *Validation result.*

As the reliability of the present method for parameter design was confirmed, virtual design of fusing parameters was carried out. The target parameter is the radius difference rate of the pressure roll of BRF. It is more difficult to optimize radius difference rate of BRF system than other fusing system, because paper transportation behavior is more complex. The complexity is due to the configurations of the system such as the nip area consisting of two regions one of which is in contact with the heat roll, and the other with the fusing pad. The fusing belt sliding on the fusing pad makes the behavior even more complex. At first, from the result indicated as Figure 9, the lower limit of the evaluation index was determined as 7.3 and the upper limit was determined as 9.6. Secondly, the optimum value and tolerance specification of radius difference rate to make the evaluation index falls within the range were predicted. The calculated relationship between the evaluation index and the radius difference rate is shown in Figure 10. The result indicates that the paper wrinkle occurred when the radius difference rate was smaller than 0.22%, and the image disturbance occurred when it was larger than 0.32%. Eventually, the optimum value of radius difference rate and its tolerance specification was determined to be 0.27% and ± 0.05% respectively. It was confirmed that the neither defects occurred in the BRF system that adopted the parameters determined above.

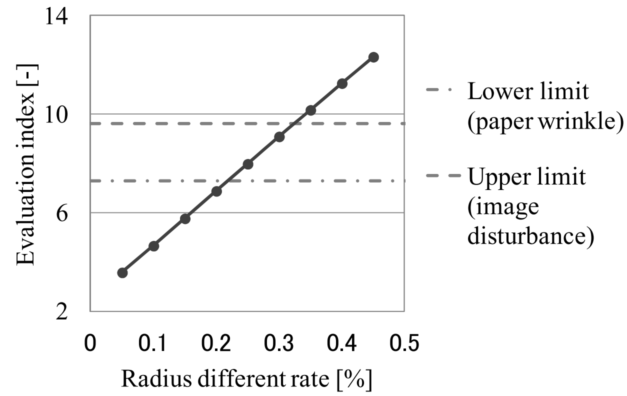


Figure 10. *Relationship between radius difference rate and evaluation index.*

Conclusion

In this study, a simulation technology to predict the occurrence of the paper wrinkle and the image disturbance caused by paper buckling was developed. The simulation model based on 2-dimensional analysis to calculate transportation force was built. By using the evaluation index that expresses the degree of axial variation of transportation force exerted on paper, the prediction of occurrence rate of the defects became possible. High correlation between the evaluation index and occurrence rate of two defects that is sufficient for parameter design of a fusing system was confirmed. By utilizing this simulation method, design of fusing parameters of BRF system was conducted, and the optimum parameter was determined.

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Author Biography

Ryosuke Takahashi holds a BS degree in chemical engineering from Doshisha Univ. In 2006, he joined Fuji Xerox Co., Ltd., where he engages in a research on electrophotography process simulation. He is member of Imaging Society of Japan and Japan Society of Mechanical Engineers.