Modeling of the Paper-wrinkle Generation Process

Shogo Matsumoto** and **Yoshihiro Harada; Core Technology R&D Center, Ricoh Company, Ltd.; Yokohama, Kanagawa, Japan

Abstract

In the present study, the paper-wrinkle phenomenon in printers is analyzed. A convenient geometry model of paper wrinkle is constructed based on the observation of the generation process and a substitutional characteristic of wrinkle generation is derived. In addition, an apparatus for quantitatively visualizing the generation process of paper wrinkle is developed in order to evaluate the phenomenon, and the validity of the substitutional characteristic is verified.

Introduction

Defects caused by sheet-feeding instability have been major obstacles in printer development due to the difficulty of the analysis imposed by enormous affectors. To tackle the problem, we analyze the paper-wrinkle generation process in the fuser unit and develop a prior evaluation methodology for it. Based on the observation of the process, a convenient geometry model of the wrinkle is constructed and the relationship between the wrinkle restrictions and controlling factors is formulated by incorporating a snapping model of the fuser nip into the geometry model. Finally "wave slope angle" is derived as the substitutional characteristics of the paper-wrinkle generation process. To evaluate the process quantitatively, an apparatus for measuring the feeding velocity distribution and visualizing deformed papers' shape is developed. Validation results show that the margin of the process can be evaluated by using the proposed substitutional characteristics.

Modeling of the Paper-wrinkle Generation Process

Snapping model of wavy deformed paper into the fuser nip

In the present study, wavy deformation of paper caused by the paper feeding velocity distribution is discussed. Based on the observation of the paper-wrinkle generation process at the fuser nip, wavy deformation of paper is modeled geometrically as shown in Fig.1.

At the measurement location of $y = y_{ob}$, the wavy deformation shape of the paper is formulated as follows:

$$l_{yob} = 2y_{ob} \cdot \tan(\beta - \theta) \tag{1}$$

$$\delta_{yob}' = \theta \cdot y_{ob} \tag{2}$$

Assuming that no slip occurs between the paper and the roller, and that the paper remains flat, except in the wavy deformed area, the wavy shape of the paper can be estimated using the paper feeding velocity distribution.

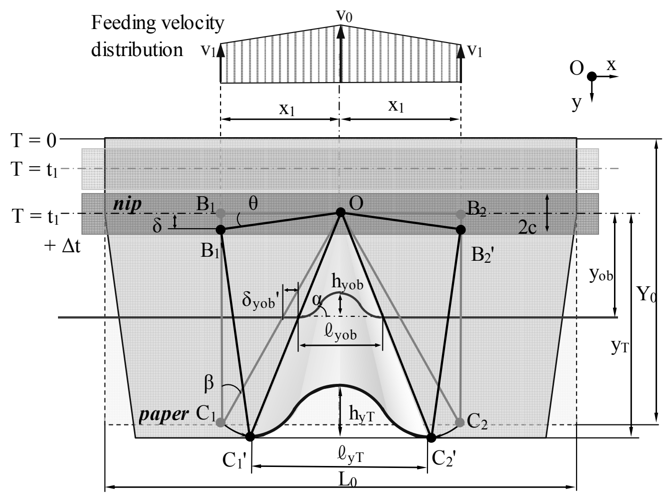

Figure 1. Wavy deformed paper model

Paper-wrinkle generation condition

The process by which the wavy deformed paper is snapped into the fuser nip area, the following three modes are defined as shown in Fig. 2

In Mode(1) [Buckling Mode], the snapped paper is buckled and a wrinkle is generated. In Mode (2) [Pass-through Mode], the wavy deformed paper passes through the nip area without wrinkling. In Mode (3) [Slip Mode], the wavy deformed paper slips through the nip area and is flattened in order to pass through the nip area without wrinkling. The limit conditions of these modes are defined as follows:

Mode 1): [Buckling Mode]

This mode defines the lower limit of the wave slope angle α that can be estimated by considering the compressed area of snapped paper as the beam element and applying the Euler's buckling load to the element.

Mode 3): [Slip Mode]

This mode defines the upper limit of the wave slope angle α that can be estimated under the condition in which the paper and the roller slip against each other in the nip area, causing the friction force to go to zero.

Mode 2): [Pass-through Mode]

This mode can be defined as the condition between above-mentioned two conditions.

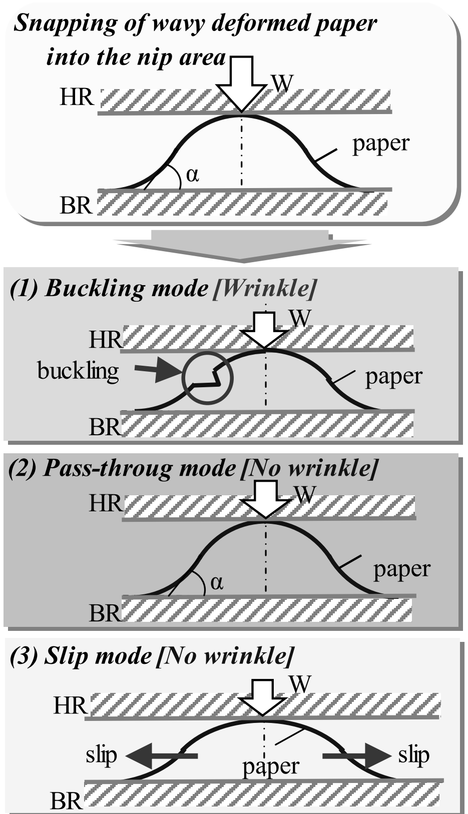

Figure 2. Snapped mode of wavy deformed paper into the nip area

Using this geometry model, the wavy deformed shape of the paper can be estimated based on the paper feeding velocity distribution and the fundamental properties of the paper (Young's modulus of the paper E, coefficient of friction between the paper and the roller μ, and the geometric moments of inertia of the paper I e.g., I). Moreover, whether the wavy deformation results in wrinkling can be evaluated using the wave slope angle as the substitutional characteristics of the wrinkle.

The fundamental properties of paper can be measured beforehand, and the paper feeding velocity distribution can be measured using the wrinkle principle analysis apparatus described in the next section.

Visualization of the paper behavior

In the present study, a principle analysis apparatus for measuring the paper feeding velocity distribution and visualizing the shape of deformed paper was developed. Figure 3 shows an outline of the apparatus.

Measurement of the paper feeding velocity distribution

The paper feeding velocity distribution is measured by detecting the interval of horizontal line patterns formed on the stripped test chart. In the present study, a high-speed line-scan camera is used to enable simultaneous measurement over the width of the paper.

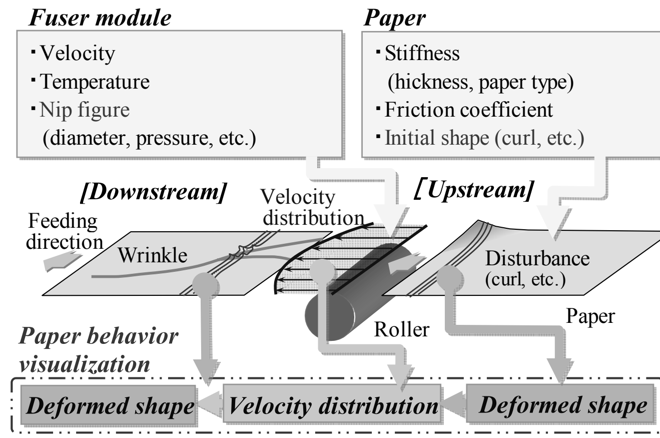

Figure 3. Overview of principle analysis apparatus

Measurement of wavy deformed shape of the paper

The wavy deformed shape of the paper is measured using the light-section method. A straight-line laser pattern is irradiated to the entrance and/or the exit of the fuser nip, and the form of the laser pattern on the feeding paper is continuously scanned by the area sensor during feeding. The deformation of the paper can be evaluated as the deformation of the laser pattern and can be quantified by converting the deformation of the pattern into height information using calibration data measured beforehand.

Results of a paper behavior measurement

In order to prevent wrinkling of the paper, the use of a roller having a diameter that varies along the longitudinal direction is common.

In the present study, several types of roller having various shapes were prepared, and the relationship between the roller geometry and the paper feeding velocity distribution and the paper deformation shape was evaluated using the above-described principle analysis apparatus. In the present paper, a roller having a smaller diameter at the center than at the ends of the roller is referred to as a pincushion-shaped roller, and a roller having a larger diameter at the center than at the ends of the roller is referred to as a barrel-shaped roller.

Results of paper feeding velocity distribution measurement

The paper feeding velocity distribution was measured under a cold condition using a striped test chart with a horizontal line pattern. Figure 4 shows the relationship between the roller shape and paper feeding velocity distribution. The paper feeding velocity distribution is shown with respect to the speed in the center part of the roller. In addition, the roller geometry is shown by the difference in diameter based on the center part of the roller.

In the case of a straight roller (roller shape: 0.0 mm) having no variation in diameter, there is almost no variation in the paper feeding velocity.

In the case of the barrel-shaped roller (roller shape is plus), the paper feeding velocity distribution exhibits a convex shape a higher feeding velocity at the center of the roller.

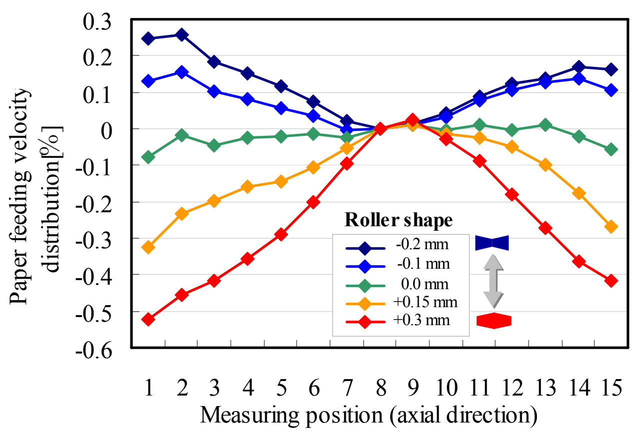

Figure 4. Relationship between roller shape and paper feeding velocity distribution

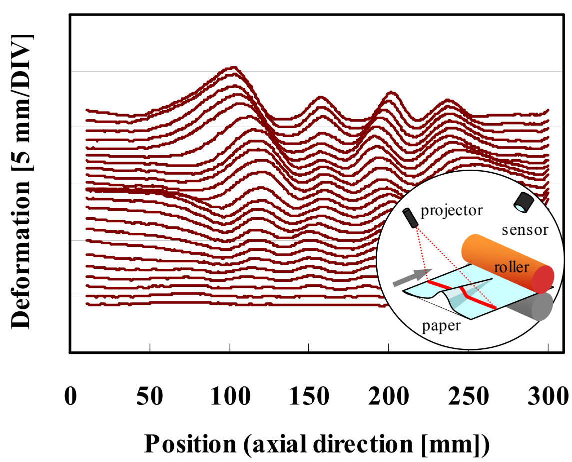

Figure 5. Transformation of the deformed shape of the paper (barrel-shaped roller: +0.3 mm)

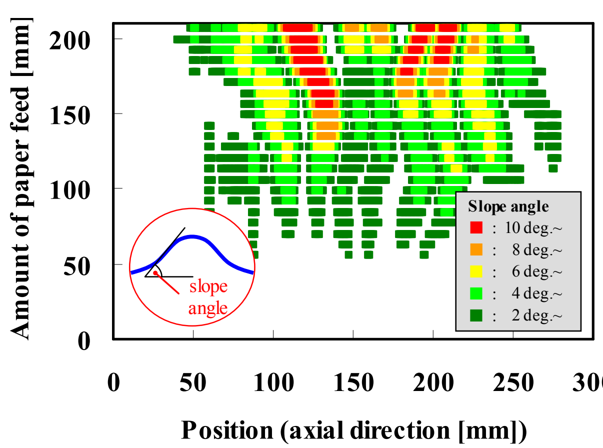

Figure 6. Transformation of the slope-angle of the wave (barrel-shaped roller: +0.3 mm)

On the other hand, the pincushion-shaped roller (roller shape is minus), the paper feeding velocity distribution shows concave shape. Therefore, the relationship between the roller geometry and the paper feeding velocity distribution can be quantified.

Measurement results for the deformed shape of the paper

The deformed shape of the paper was measured using a roller with the same shape as that used to measure the variation in the paper feeding velocity with the developed wrinkle principle analysis apparatus.

Figure 5 shows the typical transformation of the deformed shape of the paper obtained using the barrel-shaped (+0.3 mm) roller. In this figure, one line shows the deformed shape of the paper at the observation position at a certain time, and the results at each interval time (0.03 s) are plotted with these base lines shifted.

This figure indicates that the paper remains smooth at the beginning, and a wave is then generated and grows as the feeding of the paper continues.

As mentioned above, wrinkle generation in paper can be evaluated based on the wave slope angle. Figure 6 shows the wave slope angle of each area of the paper as calculated from the data of Fig. 5.

In Fig. 6, colors indicate the magnitude of the wave slope angle. This figure shows that the wave slope angle grows as the feeding of paper continues.

The experimental results reveal that the wrinkle generation area on the paper and the area having a slope angle of 8 degrees or more in Fig. 6 are in good agreement and confirm that the wave slope angle can evaluate the wave generation limit.

The wrinkle generation process is examined based on the above results. In the case of the barrel-shaped roller, the paper feeding velocity distribution exhibits a convex shape (Fig. 4), and a compressive force toward the center of the roller acts on the paper to generate the wrinkle, which grows as the paper is fed through the printer (Fig. 5). When the wave slope angle is sufficiently small, no wrinkle is generated because buckling of the paper does not occur in the nip area, and when the wave slope angle becomes sufficiently large with respect to the progress of the paper feeding, buckling of the paper occurs in the nip area, which causes wrinkling (Fig. 6).

In contrast, in the case of the pincushion-shaped roller, the paper feeding velocity distribution exhibited a concave shape (Fig. 4), and a tensile force on the paper acts toward the edges of the roller to prevent wrinkling, and stable sheet feeding is achieved.

The above-mentioned tendencies agree with the experimental findings, and the possibility of quantitatively evaluating the relationship among the roller geometry (difference in diameter between the center and the edge of roller), the paper feeding velocity distribution and the wavy deformed shape of the paper (wave slope angle and height of the wave) using the proposed principle analysis apparatus is confirmed. In addition, the prospect of appreciable of the generation limit of the wrinkle with the wave slope angle derived based on the snapping model of wave deformed paper into the nip area was obtained. The wave slope angle that describes the paper wrinkle generation limit can be evaluated according to the snapping model of wavy deformed paper in the nip area based on the fundamental properties of the paper and the paper feeding velocity distribution which can be measured by the developed wrinkle principle analysis apparatus. Finally, the margin of the wrinkle generation process can be evaluated using the proposed substitutional characteristics.

Conclusion

Based on observations of the wrinkle generation process in paper, a convenient geometry model of wrinkling is constructed, and the relationship between the wrinkle restrictions and controlling factors is formulated by incorporating a snapping model of the fuser nip into the geometry model. Finally, the wave slope angle is derived as the substitutional characteristics of the wrinkling process. In order to evaluate the process quantitatively, an apparatus for measuring the feeding velocity distribution visualizing the shape of the deformed paper is developed. The validation results reveal that the margin of the process can be evaluated using the proposed substitutional characteristics.

References

[1] Hiroyuki Seki et al., Study on Study on Wavy-Deformed Effect on Stiffness Improvement of Paper in Paper Ejection Units of Printing Devices, Proc. MIPE, (2006).

[2] Shogo Matsumoto et al., Study on Modeling of Fuser-Generated Curled Sheets and a Prediction of Dog-Ear Defect in a Sheet-Feeding Unit Using a Three-Dimensional Sheet Feeding Simulation, Proc. NIP22, (2006), 581.

[3] S. Matsumoto etal., Modeling of Paper-wrinkling Generation Process, Proc. IIP2011, No.11-9, (2011), 223-228.

Author Biography

Shogo Matsumoto received a Master's degree in Mechanical Engineering from the Science University of Tokyo in 1988 and joined the Mechanical Engineering Research Laboratory of Hitachi Ltd. in the same year. In 2008, he transferred to Core Technology R&D Center of Ricoh Company, Ltd. He has been engaged in the development of non-impact printing systems. He is a member of IS & T, ISJ and JSME.