Analysis of Electrostatic Offset

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Abstract

In the fuser process of electro-photography, defects may be caused by a phenomenon called electrostatic offset, in which image smear is caused by toner from the fuser member adhering to the paper after one rotation of the fuser member. This toner is transferred from the paper to the fuser member by electrostatic force. The occurrence of electrostatic offset depends on the electrical resistance of the fuser member and electric potential of the fuser delivery roller. In this study, we calculated the electric field of the fuser nip region, determined the shape of the fuser nip by structural calculation, and thus clarified the micro-mechanisms by which the electrostatic offset occurs. We also found that the occurrence of electrostatic offset can be predicted by the electric field strength of the fuser nip region and the electric charge distribution of toner.

Introduction

The offset phenomenon in the fuser process of electro-photography occurs when toner on the paper adheres to the fuser member at the fuser nip and re-adheres to the paper after one rotation of the fuser member, causing image smear. There are three kinds of offset: cold offset, hot offset, and electrostatic offset. The cold offset or hot offset occurs when the fusing temperature is too low or high, whereas electrostatic offset may occur even when the fusing temperature is appropriate. This is because when electrostatic offset occurs, toner adheres to the fuser member from the paper by electrostatic force acting on the toner.

The electrostatic offset problem is a significant design issue in on-demand fusers (ODF), which are found in various products of Canon. Various methods have been developed for inhibiting the electrostatic offset by controlling the electric potential and the resistivity of the fuser member [1], [2] and introduced in many Canon products. This report clarifies by simulation the mechanism by which the electric potential arrangement in the vicinity of the fuser nip and the electrical resistivity of the fuser member affect the electrostatic offset. Based on the simulation results, it then theoretically considers the advantage of controlling the electric potential and the resistivity.

ODF System

The configuration of the ODF system which is widely used in Canon products is shown in Fig. 1; (a) shows the system configuration, and (b) shows the fuser film structure. The fuser nip of an ODF is formed by the fuser film and the pressure roller and is heated from the inner surface of the fuser film by a ceramic heater on the rear of the fuser film as shown in (a).

The fuser film is composed of a base layer and a surface layer, which are respectively made of polyimide and a fluororesin as shown in (b). A conductive primer layer intervenes between the base layer and the surface layer to ensure good adhesion. The resistivity of the fuser film can be controlled by adjusting the resistivity of the surface layer. A negative voltage is applied to the primer layer of the fuser film to regulate it. The delivery roller for paper delivery is disposed on the lower stream from the nip and grounded so that its potential is zero. The electric current flows between the delivery roller and the fuser nip according to the electric potential arrangement. Electrostatic offset can be prevented by controlling the electric current. [3]

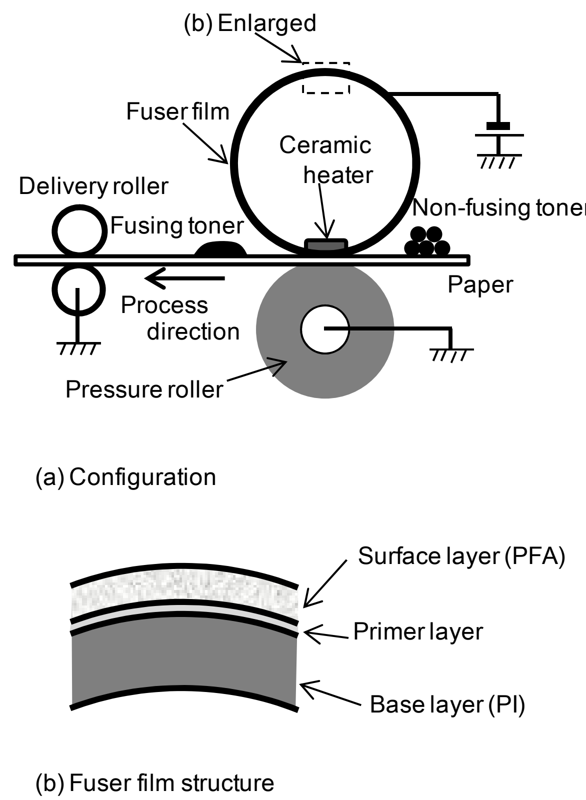

***Figure 1**. Canon ODF*

Electrostatic Offset

Offset Evaluation

An example of an offset image is shown in Fig. 2. In the electrostatic offset phenomenon, the offset image appears in the background after one rotation of the fuser film. The offset level used for evaluating the quality of electrostatic offset is defined as the difference in reflectivity between the offset toner image and the background of paper where there is no image. Here, the reflectivity is represented by the brightness measured with a brightness photometer (JIS P8148). Figure 3 shows offset images corresponding to offset levels of (a) 1.2, (b) 2.8 and (c) 11.1; the offset image is clearly visible when the offset level is larger than two.

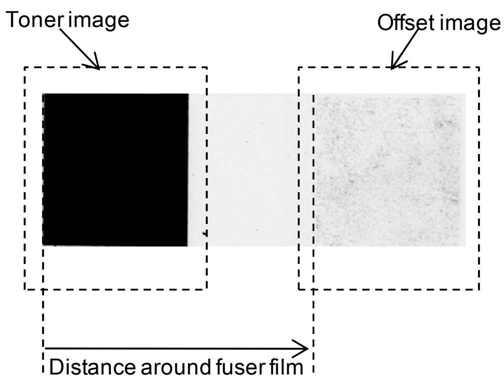

***Figure 2**. Offset evaluation*

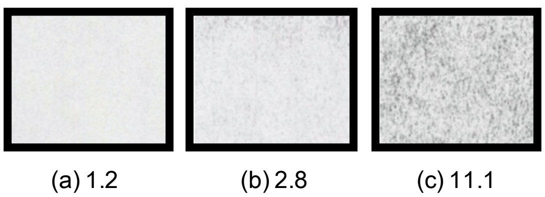

***Figure 3**. Offset level relative to image*

Dependence of Film Resistance, Electric Potential and Toner Charging

Offset levels were measured for two fuser films, a low resistivity film and a high resistivity film, having two different levels of electrical resistivity. The pressure roller was electrically grounded (potential = 0). Figure 4 shows the offset level measured at 500 V increments of the primer layer voltage of the fuser film from −2 kV to +2 kV. The figure reveals that the offset for both fuser films tends to become worse as the voltage of the fuser film is increased toward either the positive or negative direction and that the tendency is more prominent for the high resistivity film than for the low resistivity film.

Offset levels were measured in the case when the delivery roller disposed on the lower stream from the fuser nip was tentatively floated (the potential was not regulated) instead of grounded in order to examine the dependence on the electric potential arrangement. As in Fig. 4, both the low resistivity and high resistivity fuser films were used for the measurement. The measurement results are shown in Fig. 5, which reveals that the offset levels were nearly one regardless of the fuser film voltage when the delivery roller was floated and that the electrostatic offset was reduced.

In order to examine the influence of the toner charge distribution, offset levels were also measured when toner was forcibly charged positive by a corona charger. The measurement was carried out for the high resistivity film with the delivery roller grounded. The measurement results are shown in Fig. 6, which indicates that the offset level improved when the fuser film voltage was positive and became worse when the voltage was negative.

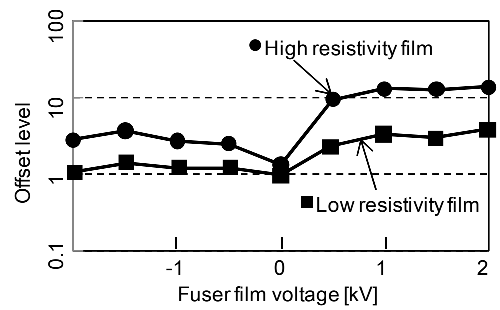

***Figure 4**. Dependence of offset level on film resistivity*

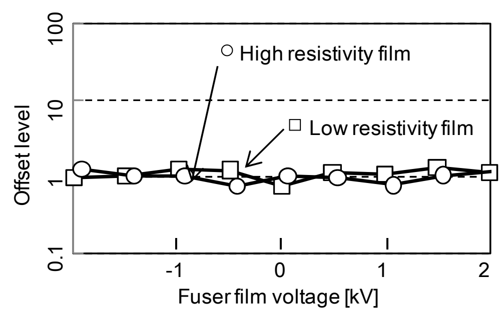

***Figure 5**. Offset in case of ungrounded delivery roller*

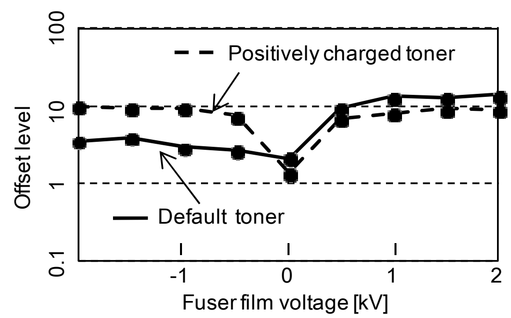

***Figure 6**. Offset in case of positively charged toner*

Mechanism of Electrostatic Offset

Simulation Model

The electrostatic offset is considered to be caused by the electrostatic force acting on toner. Therefore, the change of the electrostatic offset phenomenon depending on the fuser film voltage as shown in Fig. 4 is likely to be caused by the change of the electrostatic force acting on the toner under the electric field in the nip.

The electric field distribution in the nip was examined by a simulation method [4] in order to theoretically clarify the phenomena described in the previous section. This simulation can simultaneously calculate the physical phenomena where the electric field and the charge movement coexist, taking into account the dielectric constants of functional members such as the roller, film and paper, based on the electric conductivities of these members, according to Poisson's equation and Ohm's law. The simulation can also consider the charge transfer caused by paper traveling and discharging, and therefore can be applied to this study. Figure 7 shows the mesh model used in the simulation. The deformed shape of the pressure roller and the posture of the paper were calculated by structural analysis based on the load applied to the pressure roller, and Young's modulus and Poisson's ratios of the members, taking account of each state of contact between the paper and fuser film surface, paper and pressure roller, or between the delivery roller and paper. To the shape obtained by the structural analysis, the mesh of the air region and toner layer was added as shown in Fig. 7. The toner layer was modeled as a uniform mesh, ignoring the shape of each toner particle.

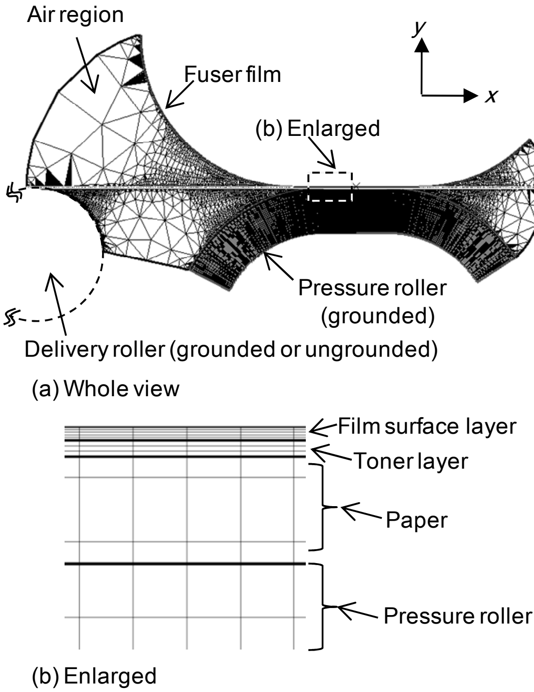

Figure 7. *Simulation model*

Simulation Results

Figure 8 shows the calculated electric field distribution in the nip in the case when the delivery roller is grounded and the primer layer voltage of the fuser film is set to +500 V. It is found that the electric field in the nip is higher toward the –y direction (direction from the film to paper) for the high resistivity film than for the low resistivity film. Furthermore, the results suggest that the negatively charged toner receives force in the direction toward the film in the nip, and that the tendency is more pronounced for the high resistivity film. The tendency matches the experimental results shown in Fig. 4.

Figure 9 shows the calculated electric field distribution in the nip in the case when the delivery roller is grounded and the primer layer voltage of the fuser film is set to −500 V. In this case, the electric field in the nip is high toward the +y direction (direction from paper to the film) and larger for the high resistivity film than for the low resistivity film. The experimental results shown in Fig. 4 indicate that the electrostatic offset becomes worse as the fuser film voltage increases also toward the negative direction. It is inferred from both sets of results that the offset is formed by the positively charged toner in this case.

In order to verify the dependence of the offset on the toner charge amount, the offset level L_{sim} in the simulation is defined as:

$$L_{sim} = \begin{cases} \chi_{(+)} E_{y0} & E_{y0} > 0 \\ \chi_{(-)} E_{y0} & E_{y0} < 0 \end{cases} \tag{1}$$

where, E_{y0} is the electric field in the y direction at the center of the nip, and $\chi_{(+)}$ or $\chi_{(-)}$ represents the ratio of the positively charged toner amount or the negatively charged toner amount to the whole toner amount, and therefore the following equation holds true:

$$\chi_{(+)} + \chi_{(-)} = 1 \tag{2}$$

The values of $\chi_{(+)}$ and $\chi_{(-)}$ are obtained by measuring the toner charge distribution. L_{sim} is the value corresponding to the electrostatic force based on the toner charge. Figure 10 shows the absolute values of L_{sim} for various fuser film voltages. The results shown in Fig. 4 indicate that the combination of the low resistivity film with the negative voltage of the fuser film minimized the offset, that the combination of the low resistivity film with the positive voltage and the combination of the high resistivity film with the negative voltage both showed moderate offset, and that the high resistivity film with the positive voltage was the worst. It is considered that the calculation results in Fig. 10 reproduce the comparative relationship indicated in Fig. 4. These results are consistent with the hypotheses that the negatively charged toner acts as the offset when the fuser film voltage is set to be positive, and that the positively charged toner acts as the offset when the fuser film voltage is set to be negative.

Figure 11 shows the calculated electric field distribution in the nip in the case when the delivery roller is floated and the fuser film voltage is set to be −500 V. The electric field is smaller by approximately two orders of magnitude than in the case when the delivery roller is grounded. The results indicate that the electrostatic force affecting the toner becomes smaller than when the delivery roller is grounded, and easily explain the experimental results shown in Fig. 5.

Figure 12 shows the absolute values of L_{sim} in the case when the positively charged toner the same as in Fig. 6 is used. As a result, L_{sim} improves when the fuser film voltage is positive, and becomes worse when the fuser film voltage is negative. These results match the tendency shown in the experimental results in Fig. 6 and prove that this simulation is valid.

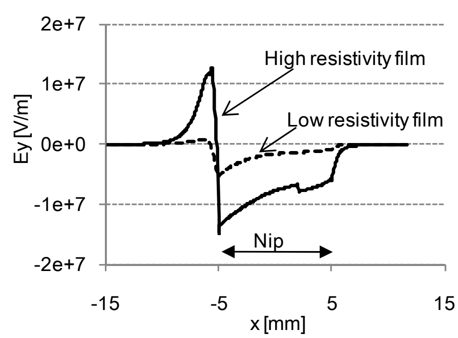

Figure 8. *Electric field (+500 V applied)*

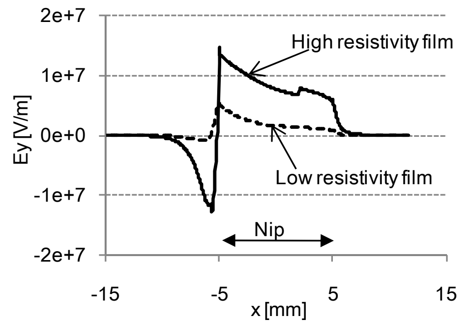

Figure 9. *Electric field (-500 V applied)*

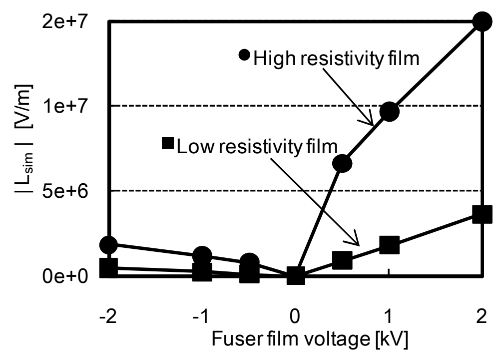

Figure 10. *Offset level calculated by simulations*

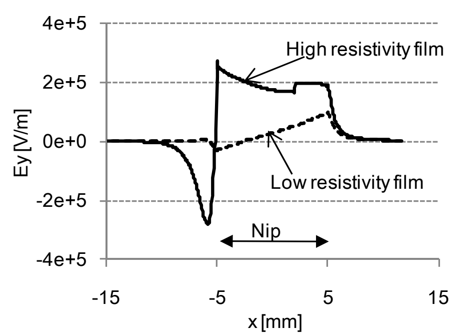

Figure 11. *Electric field (-500 V applied, ungrounded)*

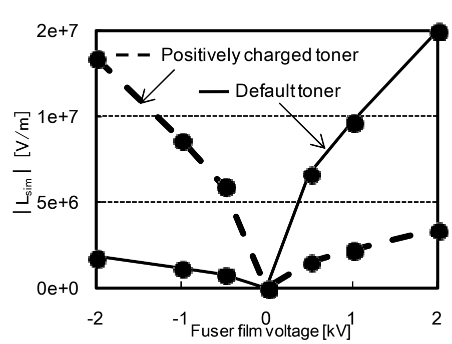

Figure 12. *Offset level of positively charged toner*

Discussion

Figure 13 explains the influence of the resistivity of the fuser film on the electrostatic offset; (a) and (b) respectively illustrate the charge states for the high resistivity film and the low resistivity film. When (a) the high resistivity film is used and the delivery roller is grounded, negative charge stays on the film surface and positive charge stays on the paper surface due to the potential difference between the primer layer of the fuser film and the paper. A significant electric field is generated by the charge and acts on the toner. On the other hand, when (b) the low resistivity film is used, the charge flows away as an electric current and therefore the electric field affecting the toner is weakened.

The electrostatic force acting on the toner can be controlled by the primer layer voltage of the fuser film. If the toner after a transfer step is charged entirely negative, the electrostatic offset can be prevented from occurring only by the applied voltage. If the toner after the transfer step, however, includes positively charged toner, the electrostatic offset cannot be eliminated only by controlling the applied voltage, in which case the electrostatic offset can be eliminated by controlling the electrical resistivity of the fuser film. The method of controlling the applied voltage and the electrical resistivity of the fuser film has been employed in the ODFs of many Canon products [1], [2], and is based on the physical model described above.

Conclusion

This study on the mechanism of occurrence of electrostatic offset in fusers based on simulation results revealed that the electrostatic offset can be eliminated by controlling the applied voltage and the electrical resistivity of the fuser film. Moreover, the simulation method is a useful design tool for predicting the level of electrostatic offset in arbitrary design conditions.

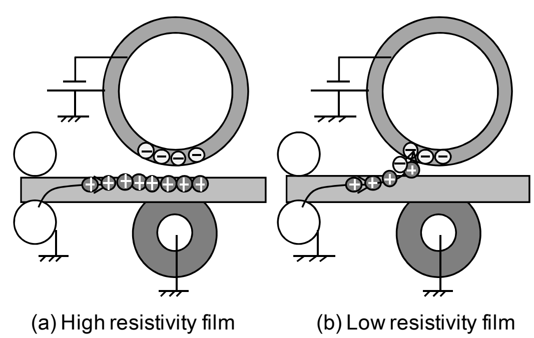

Figure 13. *Influence of film resistivity*

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Author Biography

Hiroki Eguchi received his B.E. and M.E. degrees in Physics and Electronics from Osaka Prefecture University, Japan in 2007 and 2009, respectively. He joined Canon Inc. in 2009 and has been engaged in the development of electro-photography.