Transfer Current and Efficiency in Toner Transfer to Paper

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Abstract

The transfer drum (TD) technology is one of the toner transfer processes used in laser printers. In this process, the paper is clamped and attracted to the TD. An electrical attraction occurs between the paper and the TD when a transfer voltage is applied to the TD in opposite polarity to that of the toner charge. A sufficient charge density is accumulated on the paper surface and an electric field is created between the paper and toner particles. As a result, the charged toner is electrostatically transferred from the photoconductor (PC) to the paper. Since the effect of the transfer voltage across the paper causes the electrostatic transfer, it would be important to understand the transfer phenomena in detail by studying transfer efficiency under different conditions.

The experiments for this study were carried out in a real printing process by applying different transfer voltages to some commercial paper grades under given humidity levels. The transfer current and toner amounts were measured to characterize the transfer situation. The transfer efficiency was examined as a function of transfer voltage. The experimental results show that the amount of toner transferred to the paper and the transfer current for a certain paper grade under certain humidity conditions are directly related to each other and functions of the transfer voltage. Overall, the relative humidity (RH%) is a very important variable even within fairly narrow ranges. In addition, the results show that the transfer efficiency expressed by the toner amount is in quantitative agreement with the ideal transfer profile presented by Tombs[1].

Introduction

The transfer stage is one of the six stages in the electrophotographic printing process. This stage is significant, because here the toner, printer and paper meet each other for the first time during the printing process to produce the final hard copy. The image developed on the PC can be transferred to the paper surface by using electrostatic forces, adhesive forces, thermal energy, mechanical forces or a combination of different energies[2]. The electrostatic transfer method dominates in commercial color laser and LED printers used in offices. This method can be implemented by using different technologies such as roller transfer, belt transfer, an intermediate transfer drum, a transfer corona, and TD. Irrespective of the transfer technology used, the basic principle is to generate a sufficient electric field across the paper to attract and transfer the charged toner particles of the developed image from the PC to the paper. There are two ways of electric field generation for all electrostatic marking technologies. One is ion emission from a corona charger directly onto the paper or across a paper carrier element such as a belt. The other is to apply a DC voltage via the TD or a transfer roller directly to the paper or across the carrier element.

This study is based on the use of TD technology. In the transfer stage the paper is clamped and attracted to the TD. An electrical attraction occurs between the paper and the TD when a sufficient constant transfer voltage V_t is applied to the TD in opposite polarity to that of the toner charge. Part of the transfer voltage is lost because of the resistance of the TD layers and the resistance of the contact region between the TD and the paper. Another part of the voltage is lost because of the resistance of the paper; this part is important for toner transfer and it must be high enough to cause effective polarization of paper and to accumulate a sufficient charge density on the paper surface to allow an electric field to be created between the paper and charged toner particles. The electrostatic force of this field will overcome the adhesion of toner particles on the PC and transfer them to the paper. So the transfer voltage must be high enough to overcome and transfer a large proportion of toner particles to the paper.

Transfer Efficiency

Transfer efficiency η is commonly determined as the ratio of the toner amount transferred to the paper to the toner amount developed on the PC. Sometimes the transfer efficiency is given as an evaluation function defined by the ratio of the optical image density transferred to the paper, to the optical density of the image developed on the PC[1,3]. It is more meaningful to measure the density of the image transferred to the paper before the fusing stage, so that it will be relevant to the image density measured on the PC. It was found that the optical density is not always a good indicator of the toner amount; it reaches a saturation level at a certain limit of the toner amount where the halftone image becomes solid. After this limit, any additional amount of toner will not influence the image density. Instead, the thickness of the image will be increased. Therefore the transfer efficiency can be given as an evaluation function determined by the ratio of the thickness of the image transferred to the paper to the thickness of the image developed on the PC.[1,4] The thickness of the image is usually in proportion to the number of toner layers and the layer thickness is determined by toner particle size. So this assumption requires a uniform toner particle shape and size, and for further theoretical analysis, the toner layer has to be considered as a homogeneous slab, which can be split into two layers at any thickness point.

Research Approaches

According to Ohm's law, an electric current flows in the transfer circuit, called transfer current $I_t = V_t / R_T$. Clearly, the current depends on the total resistance R_T of the TD layers, the paper, and the contact region between them. This simple idea can be used in many approaches such as:

1-Printing a similar image on different paper grades, under similar printing process parameters and environmental conditions (RH% and temperature), in which case the resistance of the paper grade will influence the transfer current. For example, high paper resistivity will produce a low transfer current. Therefore, this approach can be used to study the influence of bulk and basic properties on the electrical properties of paper.

2-Printing a similar image under similar environmental conditions on a certain paper grade by adjusting the transfer voltage for each print, in which case the total resistance R_T will remain the same each time, but the toner amount and transfer current will increase with an increase in the transfer voltage. This approach is used to examine the transfer efficiency as a function of transfer voltage.

3-Printing a similar image under many different levels of RH% and keeping all other variables constant. The same paper grade has a higher moisture content (m.c.%) at a higher level of RH%, so the volume and surface resistivity will be reduced[3,5]. In other words, the paper becomes more conductive and cannot be polarized effectively, and the surface charges leak through the paper thereby increasing the transfer current. This approach is very important to be able to understand the behavior of paper and the transfer process under different environmental conditions.

All these approaches have been used in this study.

Experiments

A commercial four-color multi-pass desktop laser printer with a transfer drum configuration was equipped with a device for adjusting the transfer voltage. To monitor the transfer process, the printer was equipped with system for measuring the transfer current. Fig. 1 illustrates the configuration. It allows the flow of current in the transfer zone to be recorded as the photoconductor revolves. For each color print, four or five revolutions are made. The first of the five revolutions is for registering the paper on the TD.

The experiments were carried out in a real printing process by applying different transfer voltages to print different commercial paper grades under given humidity levels. The transfer current was monitored and measured for each case. The transferred toner amount was weighed for each print before the fusing stage. Optical density was measured before and after fusing. A similar image in terms of size, color, halftone and location was used in all situations.

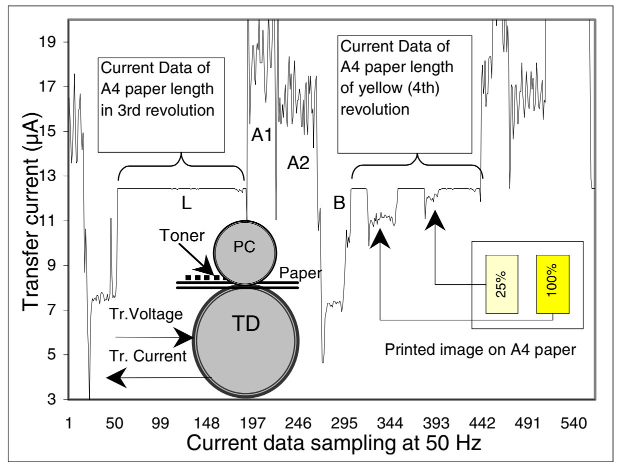

Figure 1. Measurement of transfer current. Sampling at 50 Hz.

Transfer Current Analysis

Transfer current monitoring provides a lot of data, which have proved to be meaningful in examining four-color transfer. Fig. 1 shows the current data of the transfer process at the 3rd and 4th revolutions of the TD, during printing of the image shown in the lower right corner of Fig. 1. First of all, the real current data were shifted up by 10μA to monitor small and negative values. At the 3rd revolution, where the cyan toner is transferred in this kind of engine, the straight horizontal line *L* represents the current data during the pass of A4 paper in length direction, and there is no evidence of cyan toner transfer, because the image is designed to be yellow. So the current here is equal V_t / R_T. It will be changed as a function of V_t through the adjustment, and R_T due to any changes in paper grades or RH%.

The 1st and 2nd revolutions are not shown in Fig. 1. At the 1st revolution, the paper is only registered on the TD. In this case the situation at the 2nd magenta revolution is similar to the 3rd one. The number of current data on the horizontal line *L* indicates the length of A4 paper and it can easily be calculated from the speed of the process and the sampling frequency. The effect of the width of A4 paper on the current data is reflected by the level of data on the y-axis, which means the transfer current density is measured, not just a current.

The regions *A1* and *A2* represent the current data across the rest of the TD, which is not covered by paper, so they are outside the toner transfer area. The variation in the current levels between *A1* and *A2* is due to two different dielectric materials covering the rest of the TD, so they produce two different current levels when a constant transfer voltage is applied across them. The high frequency variation in current levels of *A1* and *A2* is due to air breakdown in the air gap between the TD and PC where there is no additional resistance (paper) between them as in region *L*. Also, a high constant transfer voltage is applied over the revolution period to overcome the paper resistance prior to transfer. Region *B* represents a small sector in TD for paper feeding. The beginning of this sector represents the end of previous revolution, where the transfer voltage is reduced in one step to the minimum level. At the end of this sector, the transfer voltage starts to jump again in one step towards the optimum constant level relevant for the next revolution.

At the 4th revolution, where the yellow developed image is transferred from PC to paper, the changes in current data due to the transfer of toner is clearly indicated to show the difference in toner amount transferred to a similar image area with a different gray-scale percentage (25% and solid). In examining the change in the current due to toner transfer, the electrical interaction between PC and TD circuits should be considered. In fact, the main target of the PC circuit is to develop a negatively charged toner σ_{toner}, and the main target of TD circuit is to produce a surface charge on the paper opposite to that of the toner to ensure the electrical interaction. The surface charge is bonded by the polarization effect to the opposite surface charge on the other side of the paper. When the charges carried by the toner particles σ_{toner} neutralize the same amount of the charges on the paper surface σ_1, the same amount of the charges on the other side of the paper σ_2 will be free to leak away within the TD circuit, creating a current component in opposite direction to the original current transfer. The net value of the current outflow during the dynamic transfer process is called[6] "dynamic current density". In this paper the variation in the transfer current caused by toner transfer with variation of several parameters, has been considered to characterize the transfer situation.

Experimental Results

Figure 2 shows the toner amount transferred to the paper as a function of transfer voltage. The test was repeated twice for 80 g/cm^2 uncoated paper (80, Trial-1 and 80, Trial-2) to show that the measurement is highly reproducible. In another test (100, Trial-1) conducted under similar conditions, the toner amount transferred to 100 g/cm^2 coated paper is more than in the previous trials.

These results show that the paper grade has great influence on the efficiency of toner transfer. This is due to the electrical properties of the paper such as its volume and surface resistivity. It is also clear that the behaviors of the experimental transfer curves are similar to the behavior of the ideal transfer profile discussed by Tombs[1].

Figure 3 shows that the variation in the dynamic transfer current density and the amount of the toner transfer to 80 g/cm^2 uncoated paper are directly related to each other and functions of the transfer voltage. The current curve behaves similarly to the ideal transfer profile. It indicates the surface charge neutralized by the transferred toner particles. Therefore, the current curve can indicate the transfer efficiency as well. By interpreting the current curve from toner charge transfer and dividing it by the toner amount curve, the average q/m of the toner can be predicted.

Figure 4 shows the optical image density before and after the fusing stage as a function of the transfer voltage. There is a difference both in the slope and saturation level of the unfused and fused curves. Yet, the curves present the transfer efficiency similarly to the current and toner amount curves. This provides additional support for using the dynamic transfer current density to be used as a tool in characterizing the toner transfer efficiency and different transfer situations.

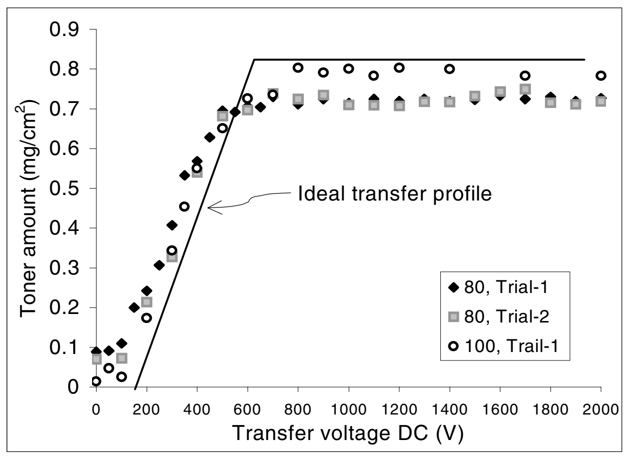

Figure 2. Toner amounts transferred to two different paper grades under similar conditions and different transfer voltages.

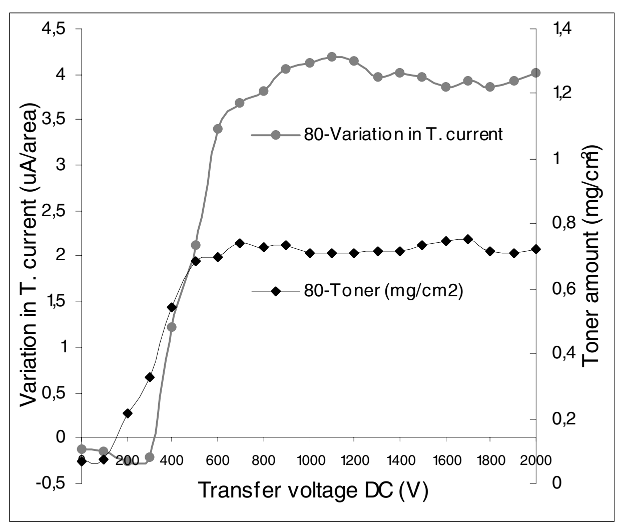

Figure 3. Transfer efficiency presented by the toner amount and the variation in dynamic current density as functions of transfer voltage, with all other variables being constant.

Figures 2, 3 and 4 show some transfer of toner to paper, even though the transfer voltage is in the range between zero and 200 V, which is not enough to create any surface charge on the paper surface. This might be due to minimal contact between the developed image and the paper surface (no air gap or very small), or the attraction voltage which is used to register the paper to the TD.

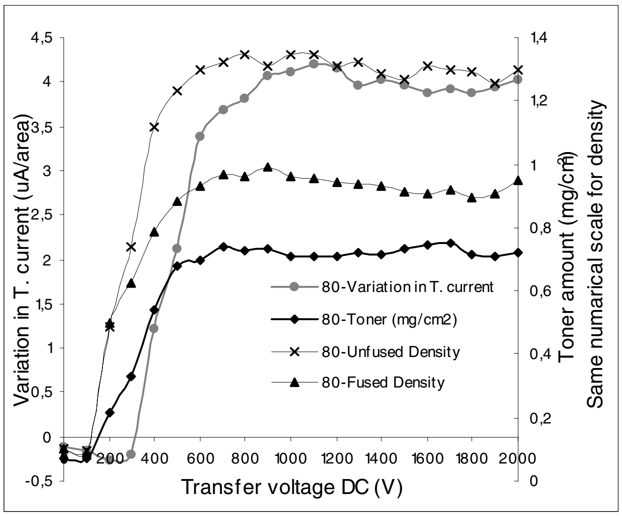

Figure 4. Transfer efficiency presented by optical density before and after fusing, together with the toner amount and the variation in dynamic current density, all as functions of transfer voltage.

Negative values of current variation in the transfer voltage range (0-300 V) appear because the electric field created by the toner charges is higher than the fields created by transfer voltages along the range mentioned. The current variation will reach zero at the point where the summation of both fields equals zero (both electric fields have equal values in opposite directions). This point is somewhere around a transfer voltage of 300 V.

Each point on the slope of all these curves is an expression of the remaining force of toner adhesion to the PC, It is decreased gradually as the electrostatic force increases until a certain value relevant to the approximate transfer voltage of 600 V is reached.

Figure 5 shows how the moisture content of paper influences the variation in transfer current during toner transfer. An increase in the RH% of ambient air results in an increase in the m.c.% of the paper, in turn decreasing the volume and surface resistivity of the paper. In this situation the transfer efficiency indicated by the variation in transfer current will be impaired[3]. The sensitivity of the transfer current to moisture changes is remarkably high.

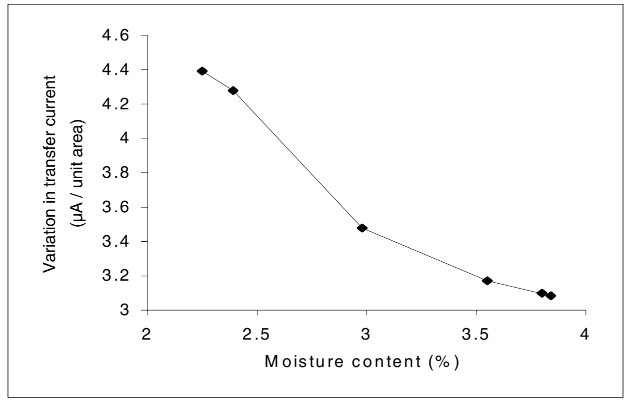

Figure 5. The influence of moisture content of paper on the variation of transfer current.

Conclusions

The transfer efficiency was examined from the viewpoint of variables influencing the toner-paper process interactions, such as transfer voltage, transfer current, toner amount, paper grades and environmental conditions. The efficiency of toner transfer was presented as a function of transfer voltage in terms of toner amount, variation in the dynamic transfer current density and the optical image density before and after fusing stage, and they were all found to be in good quantitative agreement with the ideal transfer profile of Tombs.[1]

According to this study, the measured transfer current responds sensitively to any change in the materials, such as the bulk and electrical properties of the paper and the *q/m* of the toner. It is also sensitive to image and process variables such as halftone, size and location of the image and transfer voltage, and relative humidity. For this reason, the measured transfer current could be used as tool for further studies such as *q/m* measurements and toner adhesion on to the PC.

According to the findings of this study, the transfer voltage creates a surface charge density on the paper, which determines the extent of transfer through the net current over the total resistance. When the surface charge is changed for some reason, the net flow of the dynamic transfer current will change in the opposite direction.

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Biography

M. Sc. student Hussain AL-Rubaiey studying and working on the field of electrophotography at Helsinki University of Technology in the Laboratory of Media Technology. Firstly, he received his B.Sc. Physics from University of Baghdad. Dr. Pirkko Oittinen is Professor of Media Technology at Helsinki University of Technology.