Controlling Fusing Parameters by Optical Image Quality in Electrophotographic Printing

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ABSTRACT

Particle-based electrophotography is the premier digital printing method today. From the quality standpoint its competitiveness has suffered from print unevenness. The study addresses the issue to what extent improvements can be achieved by adjustment of variables in the fusing stage.

INTRODUCTION

Fusing is the stage where the toner in electrophotography and other particle based digital printing methods is sintered, spread and penetrated into paper. As it is the last stage in the process, it dominates the final physical and optical print quality. In any contact fusing method, the fusing energy is applied as pressure, and as conductive heat transfer and fluid flow phenomena. Three groups of parameters control fusing quality: toner, paper and process parameters /1,2/, as listed in Table 1.

<table>
<thead>
<tr>
<th>Toner properties</th>
<th>Paper properties</th>
<th>Process parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Specific heat capacity</td>
<td>• Specific heat capacity</td>
<td>• Hot roll surface temperature</td>
</tr>
<tr>
<td>• Thermal conductivity</td>
<td>• Thermal conductivity</td>
<td>• Average nip pressure</td>
</tr>
<tr>
<td>• Surface energy</td>
<td>• Moisture content</td>
<td>• Dwell time</td>
</tr>
<tr>
<td>• Glass transition temp.</td>
<td>• Surface energy</td>
<td>• Toner pile height</td>
</tr>
<tr>
<td>• Viscosity</td>
<td>• Roughness</td>
<td>• Ambient temperature</td>
</tr>
<tr>
<td>• Particle size</td>
<td>• Porosity</td>
<td>• Nip width</td>
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</table>

It is assumed that the toner on the peaks of the paper profile gets very glossy as a result of nip calendering. If the paper is very rough, the toner in the valleys of the surface does not get into good contact with the roller, so the area remains matte. Since the calendering effect is proportional to the nip pressure, it is expected that reduced nip pressure results in reduced gloss and in optical density variations. Therefore, reduced pressure should be compensated by increased dwell time (or nip width) to achieve the same level of physical fusing quality and to improve optical quality /2,3/. 
The nip width is proportional to the thickness and elastic modulus of the elastomer layer \(4\), therefore by increasing the thickness of a softer layer, the nip pressure is reduced and nip width is increased. This paper is focused on the above adjustable fusing parameters to control optical image quality within acceptable level of physical quality such as image adhesion. Figure 1 shows the limitations of fusing range as a scale for the experimental fusing units.

From the equation \(3\) \[ K = f\left( \frac{P t^2}{MD}, \frac{T}{T_a} \right) \], the fusing quality is a function of two dimensionless groups; \( \frac{P t^2}{MD} \) and \( \frac{T}{T_a} \), where \( K \) is fusing quality, \( P \) is average nip pressure, \( t \) is dwell time, \( M \) is developed mass of toner per unit area on the substrate, \( D \) is average diameter of toner particle, \( T \) is fusing temperature, and \( T_a \) is the ambient temperature. For comparison between image quality of a hard and a soft nip, dwell time is a significant variable. Further adjustment of soft nip load and consequently the nip width is also possible \(5\).

**EXPERIMENTS**

Four different contact fusing technologies were used in this work. They are described as following:

1st) **Hot rollers**; in this unit, both fixing and backing rollers are heated by tungsten-halogen lamps, with adjustable temperature and speed. It was used as a reference for the limitation near by heat set offset, because it is applying high pressure, and supplying high heating energy for both image side and back paper side.

2nd) **Hard nip**; in this technology, only the fixing roller image side is heated to a temperature of 165°C, and the contact area between fusing roller and back roller (nip width) is 4mm, with a nip pressure of 45kPa and dwell time of 40ms.

3rd) **Soft nip**; it is modified from the previous one by replacing the elastomer coated layer of the back roller with a softer one of different elastic modulus. This is to obtain softer nip with pressure of 30kPa, and in turn this modification produces wider nip (6mm) and longer dwell time (60ms) with constant load. The speed and temperature are kept the same as in hard nip. It is important to mention that the new elastomer coating material of the back roller has different thermal conductivity than the original one, but that will not affect the final temperature of fusing nip because this roller is not a heating roller, it is just a pressure roller.

4th) **Belt fusing**; as it is not so easy to obtain flat and wider nip between two rollers than in soft nip, belt fusing unit with nip width of 10mm was used for the other end of fusing latitude near by cold offset. The unit consists of a belt of high thermal conductivity wound around two rollers, the one far from the nip and the other forming the nip with back heated roller with adjustable pressure. In this design, the heating energy is supplied through the backside of the substrate by
the heated back roller and partially to the image side by the belt transferring the heat from the
roller far from the nip. The idea is to reduce the heating energy supplied directly to the printed
image, for better quality. In these technologies, the latitude of fusing parameters is controlled by
heat and cold offsets, and printed image quality. So, the range of process variables is flexible
enough to study their influences on optical print quality.

Five paper grades were used in this experiment. The test target was designed to meet of the
measurements requirements and further investigations of the results. At acceptable levels of
fixing strength and image adhesion, optical image density, and gloss and its variation were
measured.

Gloss variation was of prime interest. Preliminary experiments suggested that it responds far
more sensitively to adjustments of fusing variables than optical density. Gloss variation was
measured using modified gloss analyser at the 20° incident-reflectance angles for a minimum
image area of 44mm × 46mm. The measurement is based on the concept of band-pass filtering of
image. Three bands were used. The coefficient of variation in each range can be used as a
measure for the strength of gloss variation. The scale of gloss variation, which was used in
Figure 3 is a measure for the size of unevenness and it is obtained by dividing the coefficient of
variation from the band >5mm by the coefficient of variation from the band <1mm [ (>5mm) /
(<1mm)]. The scale is lowest for fine-grained and highest for coarse-grained structures.

RESULTS AND DISCUSSION

As a result of operating four different sets of fusing parameters within acceptable results of the
physical fusing window, each of the four fusing units produces different density and glossiness.
According to the density measurements, different grey scale reproductions were produced from
the same image at certain grey scale %. In Figure 2, the higher level of densities obtained by hot
rollers at each grey scale is due to heating energy being supplied from two opposite directions by
both fixing and back rollers, which causes fast toner melting, and at the same time spreading
widely under high pressure. As a result, image enhancement from a good level of coverage by
high dot gain was obtained. From the black solid print, Figure 3 shows that the gloss variation of
the image fused by the hot rollers is the highest. The gloss variation is an indication of print-
surface unevenness. The rougher the print surface, the higher the gloss variation.

![Figure 2](image) Grey scale densities printed on 100 g/m² coated paper.
Reducing both energies, the heat and the pressure, and instead increasing the nip width as in belt fusing; less optical density in all grey scales indicates less dot gain as is evident from Figure 2, which in turn means high accuracy (grey scale image reproduction), and less gloss variation from smooth print surface. In belt fusing the optical image quality is improved.

Between these two limits, the results from hard nip and modified soft nip show the critical fusing factors influencing optical image quality. Table 2 shows that even the average gloss of solid green and black prints are higher from the soft nip, but still -for both colours- the gloss variations are lower at all the wavelength reflectance ranges. It is also clear from Figures 2 and 3 that the soft nip produces better optical image quality with less dot gain and lower gloss variation than the one produced by hard nip. The only difference between these nips is just replacement of the coating material of the back roller by a softer elastomer. As it was mentioned, this modification has increased the nip width and dwell time, and reduced the pressure. It is expected that with the soft nip, there will not be a considerable change in the fixing strength. Simply, the fixing quality is related directly to the nip pressure in one order of magnitude and to the dwell time in two order of magnitude /5/.

Table 2    Gloss and its variation of solid prints on 80 g/m² paper.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Gloss</th>
<th>&lt;1mm</th>
<th>1-5mm</th>
<th>&gt;5mm</th>
<th>Scale</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hard nip/Green</td>
<td>9,4</td>
<td>60</td>
<td>17</td>
<td>6,5</td>
<td>0,11</td>
</tr>
<tr>
<td>Soft nip/Green</td>
<td>12</td>
<td>54</td>
<td>14</td>
<td>5,3</td>
<td>0,10</td>
</tr>
<tr>
<td>Hard nip/Black</td>
<td>2,8</td>
<td>47</td>
<td>14</td>
<td>5,7</td>
<td>0,12</td>
</tr>
<tr>
<td>Soft nip/Black</td>
<td>3,6</td>
<td>45</td>
<td>13</td>
<td>4,6</td>
<td>0,10</td>
</tr>
</tbody>
</table>

The results show that the image quality obtained by belt fusing is better. Its energy consumption is also lower and lifetime longer. Now, it is understandable to recommend an adjustable fusing system in industrial electrophotographic machines to allow different applications with desirable quality. The claim is not all quality attributes are controlled produced by the fusing stage, but as it is the final stage in the electrophographic process, therefore it has the final and definitely a crucial effect on achieved print quality. Some of the fusing parameters of this study that have clear influence on optical image quality could be adjusted within acceptable fusing range. To ensure high performance, these parameters could be adjusted automatically according to the density and gloss variation measured from the first print as functions of different substrates and image coverage.
**CONCLUSION**

The study focused on the role fusing configurations and fusing parameters have in controlling print unevenness. The influences proved to be considerable. This suggests that improvements can be achieved by adjustments of the parameters based on a feedback control loop in fusing units.

**REFERENCES**