Thermal Gradient Mechanism of Line Crossing Anomaly

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Order-of-strokes tests were conducted to investigate a potentially misleading feature of line crossings in a specific category, namely intersections of moderately embossed handwriting and laser printing, in which rarely encountered crossings of laser printing over pre-existing pen strokes mimic the opposite and more normal order.

Introduction

Tests described in this paper explore a phenomenon which may be encountered during order-of-stroke determinations of intersections involving laser printing and handwriting (e.g., signatures), in which the writing is appreciably embossed into the page, such as from ballpoint (greasy ink) or roller-ball (fluid ink) pens. The line-crossing anomaly that prompted this study was encountered during ordinary casework, although only the basic phenomenon will be presented here, independent of any particular case.

Documents are ordinarily printed first and subsequently signed, rather than being printed onto presigned pages. Observations are routinely made of crossing strokes on questioned documents. This is to detect whether a page signed in blank, or essentially so, has been used to construct a will document or other instrument after the fact by subsequent printing. Intersections where the printing and signature overlap are the obvious places to examine when making such determinations, although a recent paper addresses non-overlapping instances by observing background printer spray within the written strokes (Aginsky, 2002).

The printing medium addressed here is conventional monotone (black) laser printing, not ink-jet or other methods; and the crossings involve moderately embossed ink writing. Laser printers commonly employ powdered toner consisting of carbon-pigmented polymer that is electrostatically applied in character shapes to the surface of the paper. The toner is then fixed to the page as it passes between cylindrical rollers before exiting the printer. The roller on the printed side of the paper is heated from within so as to cause the pigment particles to fuse together and to the paper. Such printing, although pressed into the paper fibers, does not really soak in and stands, in some degree of microscopic relief, above the paper surface.

In the case of crossings involving conventional, greasy-ink ballpoint pen writing, the shine of the ink smear over laser printing is rather obvious by its bright reflection of glare-angle illumination. Microscopic study of such crossing strokes indicates that the shine is due to burnishing of the fused laser toner by the pen tip, as well as thin-film interference coloration by the ink layer similar to other oily films. The burnishing effect is confirmed by microscopic observations of writing over laser printing with a dry ballpoint pen empty of ink. Under the microscope, the increased sheen of fused laser toner at an inkless pen crossing is easily seen as a rounded groove with a nearly mirror-finished black surface, whereas adjacent fused toner exhibits a pressed-flat fine-grained surface sparkling with an irregularly mottled pattern of innumerable highlight reflections. In the case of fluid-ink roller-ball pens, the burnishing effect is the same, but the fluid ink's behavior and contribution to the final appearance of the crossing is somewhat more complex. For crossings by fluid-ink pens with softer tips, the fluid ink can either (a) wet the substrate for a sufficient period of time to dry in place, (b) run off or through the substrate but leave traces on top, or (c) some variation of either. There may be an overall darkening effect on underlying laser toner by virtue of the dried film resulting from fluid ink, ordinarily recognizable microscopically as a coloration of the highlight reflections of the underlying fused laser toner.

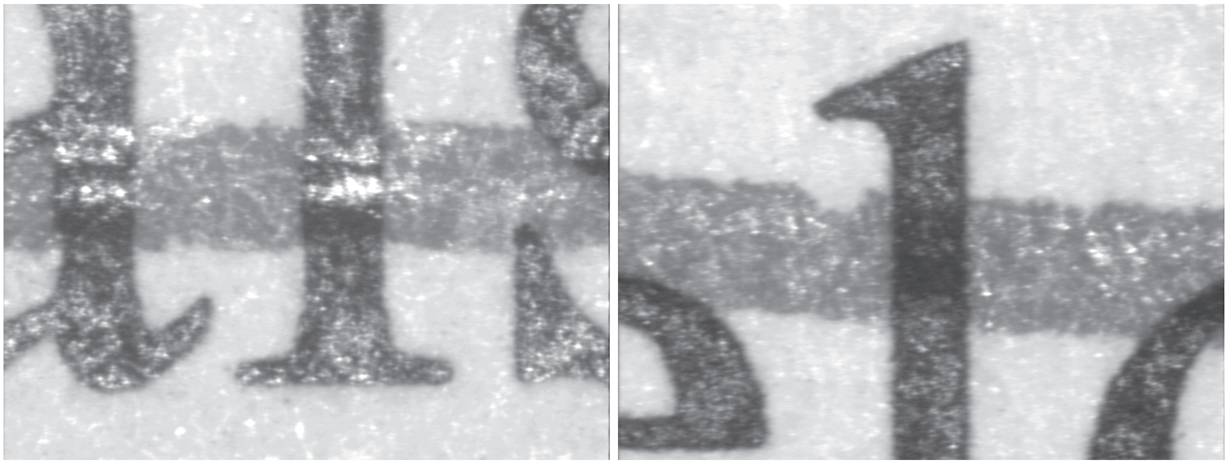

Figure 1. Ink stroke over laser printing (left); laser over pre-existing embossed ink stroke (right).

Experience has shown that crossings by fluid-ink pens over laser printing are less likely to produce a stripe of increased sheen than are conventional, greasy-ink ballpoints, the latter of which are unfailing in this regard. Thus, for intersections of greasy-ink ballpoint writing with laser-printed characters, a line of mirror shine at the crossings is unambiguously indicative that the writing crossed over the printing, there being no plausible mechanism for producing such increased sheen for toner applied over the writing. However, fluid-ink writing, owing to the net darkening effect it may have on the toner surface underneath, is susceptible to being mimicked by the phenomenon described below.

The Anomaly

It was found that text characters laser printed onto existing embossed handwriting exhibit darkening roughly coincident with the underlying ink stroke, which may give the erroneous impression that the ink crossed over the toner. In simple terms, it looks like a dark band across the toner surface where the writing "crosses," although the writing is actually underneath and the laser toner is on top. Figure 1 compares a fluid-ink stroke crossing over laser printing at left, with laser printing applied over a pre-existing ink stroke and exhibiting the anomalous dark band at right. This appearance is mentioned by Planty (1997) in reference to interaction of test laser printing with conventional ballpoint ink lines. Grayscale photographs in that journal article contrast the pronounced shine of ballpoint marks over laser printing with the "dullness along with discontinuity of the pen line" of laser printing over ballpoint marks.

The microscopic appearance of the darkened region is similar to that of incompletely fused toner, lacking the reflection highlights or sparkles exhibited by adjacent surfaces of normally fused toner which has been subjected to the intended thermomechanical conditions of heat and pressure. Although photomicrography of this phenomenon is a photographic challenge, live stereomicroscopy gives the compelling impression that the darkening is related to sheltering of the area from direct contact with the fusing roller by the protective furrow of the writing embossment. Microscopy further reveals a thick and opaque toner layer and contraindicates show-through by the underlying ink as a cause, although not absolutely ruling out the possibility of a physical effect of underlying ink on the subsequent laser printing. Such an ink-related effect could hypothetically result from: (1) influence by underlying ink at the toner application stage at which the powdered toner image is electrostatically transferred to the page, or (2) migration of the ink upward through the toner layer before, during, or after the fusing process. It should be noted that an intact layer of laser toner, intensely pigmented with carbon black, is too opaque to detect substrate brightness differences because of light absorption and scattering. Thus, the experimental problem is one of differentiating embossment-sheltering effects from ink-related effects on the surface appearance of laser printing applied over pre-existing writing.

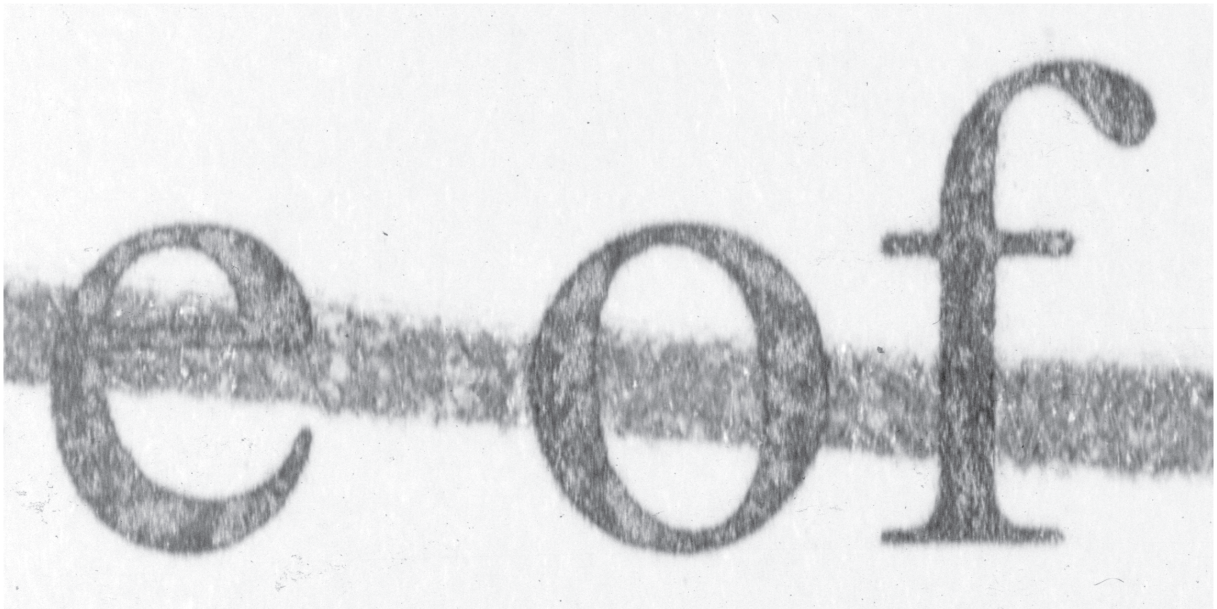

Figure 2. Laser printing over a pre-existing, unembossed black fluid ink stroke.

Methods and Materials

Test printings employed hot-roller/cold-roller fusing laser printers, primarily Hewlett-Packard LaserJet 5000 and Xerox N4525. Writing strokes were made with various pens including Sanford Uni-Ball Onyx (fine point), Pilot Precise V7 Rolling Ball fine and extra fine, Quill Durastone 95 Roller Ball, Sanford Sharpie fluid ink pens, and a variety of common conventional-ink ballpoint pens. Bright red and bright blue ink versions of the Uni-Ball pen were also employed in monitoring toner voids. Papers ranged from 20-pound multipurpose to 28-pound bonds. Photographs were made with axial illumination introduced via polarizing (Figure 1) or plain glass (Figures 2 and 4) pellicles; Figure 1 consists of two NTSC video frame stills; Figures 2, 3, and 4 are grayscale reductions from Ektachromes.

Tests were conducted to explore the effects of pre-existing writing on subsequent laser printing and to isolate effects purely due to underlying dried ink from those purely due to physical embossment of the underlying writing:

Pre-Existing Ink Only (no embossment):

Text was laser printed over pre-existing ink strokes which had been applied with a light touch to avoid embossing the paper but were generously inked with various black fluid inks as well as conventional ballpoint inks. The result was that no microscopically visible trace or effect of the underlying ink in the unembossed writing could be seen on the surface of the laser printing. A typical example is shown in Figure 2. Note the absence of any visible effect on the mottled surface pattern.

Pre-Existing Embossment Only (no ink)

Text was laser printed over pre-existing writing embossments written with various styli, including empty ballpoint pen mechanisms. Surface-only embossments were made with the paper on a desk; through-and-through embossments were made with a writing pad of several sheets of underlying paper. Widths and positions of "crossings-under" of the nominally invisible (inkless but embossed) writing remain locatable by low-angle illumination, as shown in Figure 3. The result was observation of the same darkening of the laser printing at intersections with the pre-existing uninked writing embossments as with inked writing. The effect was present with surface-only as well as through-and-through embossments. The dark banding which appears across the highlight pattern is shown in Figure 4.

These experiments isolate the embossment-related variables of pre-existing writing from those related to ink and establish the darkening as an effect of topology rather than ink.

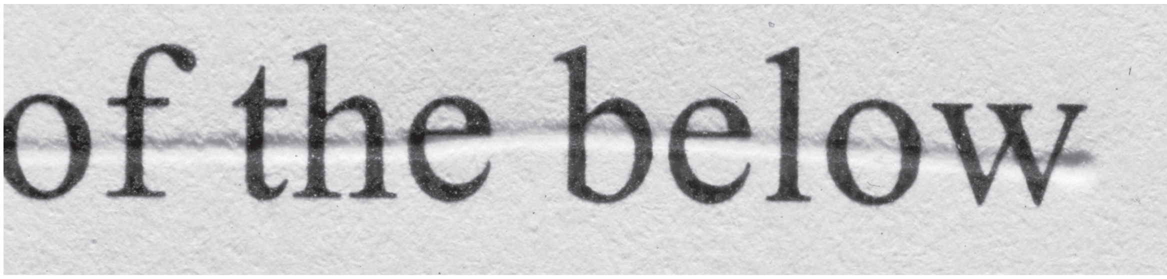

Figure 3. Raking light location photo of laser printing over pre-existing uninked embossment.

Figure 4. Axial illumination close-up of right-most word shown in Figure 3. Note dark band.

Whether the pre-existing writing embossment is inked or not, the appearance of the darkened region of laser toner applied over it is the same—velvety blackness. In most instances the darkened area is noticeably narrower than the underlying embossment, consistent with the expected thermal gradient within the embossment where the toner is increasingly out of direct contact with the fusing roller surface. The properly fused surfaces at the shallow edges of the embossment are understandable by considering the local topology and thermomechanical conditions of heat and pressure. These include heat flow into softening toner from adjacent toner, which in turn is directly in contact with the hot fusing roller's surface, any degree to which roller pressure can restore direct contact near the embossment edges, and the topological effect of the toner layer filling in the shallows to some extent.

Figure 5 diagrams representative size relationships between ballpoint-pen-tip diameter (1 mm), embossment width (0.5 mm), paper thickness (0.1 mm for bond), and diameter of the cylindrical fusing rollers (1 inch). The thickness of laser toner is not shown at this scale. Note the gap where fusing roller surface is unable to maintain contact inside the narrow embossment.

Discussion

The anomaly having been characterized, it remained to reduce the findings to a systematic method with which to approach this type of examination so as to avoid confusing it with other effects. Fortunately, most hard pen tips leave the aforementioned burnished sheen in the process of being passed cursively across laser printing. This allows the elimination of many sources of possible uncertainty. If there is a "band of difference" across laser printing coincident with a pen stroke, all ink-first possibilities are moot if the band exhibits brighter specular glare than surrounding toner, assuming microscopic confirmation that the glare is from an opaque toner layer rather than from underlying ink peeking through voids. Conversely, if the band of difference appears darker than adjacent normally fused toner surface but the writing is not embossed into the page, then embossment sheltering cannot be involved. In that event, again

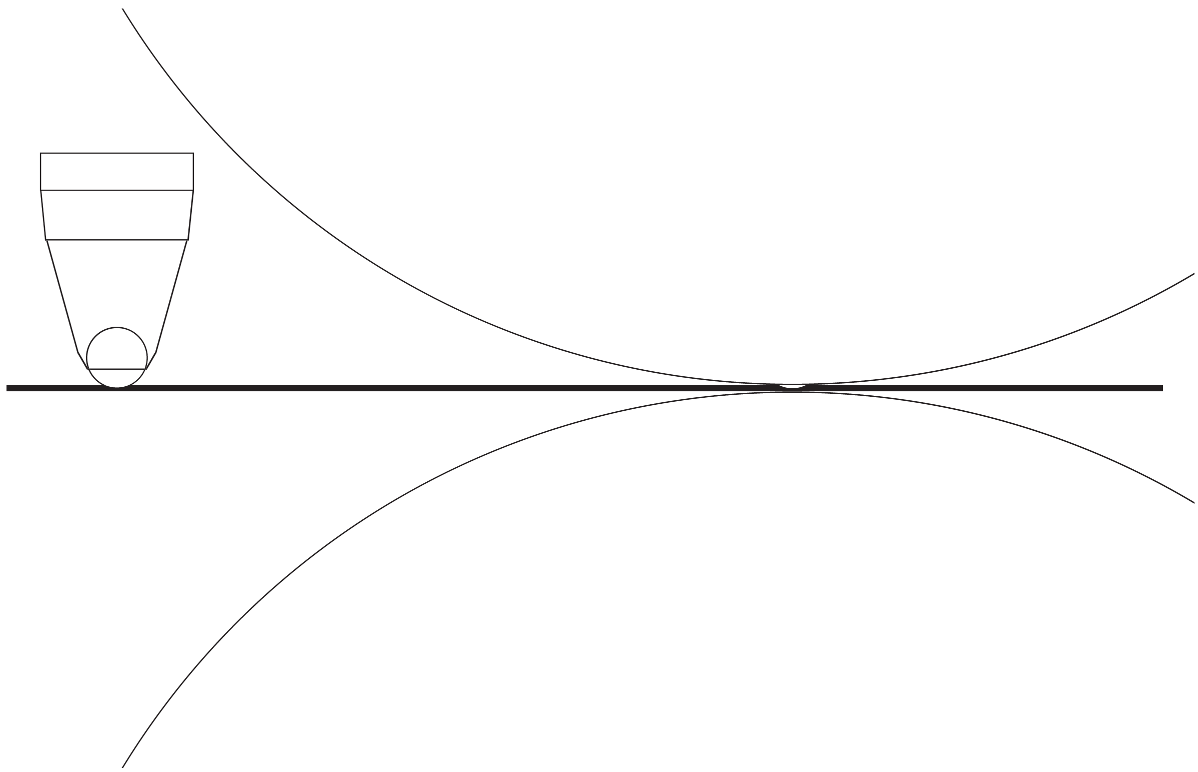

Figure 5. Scale of pen ball, paper (black horizontal), and fusing rollers; toner layer not shown.

assuming microscopy confirms an unbroken, opaque layer of toner, then ink residue on top of the toner is the conclusion.

Possibly the best news of all is the realization that the root cause of the anomaly (sheltering of toner within grooves previously embossed into the paper) has an inverse relationship with the most plausible source of confusion, i.e., fluid ink applied on top of laser printing. This means that if the pen pressure is heavy enough to emboss the page, then it is likely to be heavy enough to burnish any pre-existing laser printing it crosses. On the other hand, if the pen pressure does not emboss the page, thus being so light as to explain a lack of burnish shine, then any discolored or darker band is only explainable by the ink being on top, because the embossment-sheltering mechanism is not available.

Thus, the primary area of potential confusion to be scrutinized involves crossings of laser printing by fluid-ink strokes heavy enough to emboss the page but in which a darkened band is visible on the toner surface rather than a shinier band. It was noted that, using glare-angle illumination, microscopy could differentiate between the type of darkening caused by an overlying ink film and that resulting from the anomaly. Ink films cause a darker band (with respect to the adjacent toner) by virtue of their coloring and/or obscuring of the reflection highlights of the underlying fused toner surface. The dark band resulting from the anomaly lacks the mottled pattern of fusion shimmer when observed under the microscope, having never been in contact with the hot fusing roller. The utter blackness of such toner, at its uncalendered stage of fusion, is differentiable from the type of darkening caused by an ink film on a toner surface properly fused under pressure by direct contact with the hot roller.

Results

The following step chart for examining intersections of embossed ink writing and laser printing is based on results of the aforementioned observations. This step chart applies to intersections of moderately embossed writing and laser printing of the common hot-roller/cold-roller fusing variety, not to radiant fusing systems.

(1) Microscopy, wiggling glare angle illumination:

(2) Categorize the appearance of the intersection with respect to adjacent fused toner surface:

(3) Brighter band, e.g. burnish or ink glare: go to (10).

(4) Darker band: go to (6).

(5) No visible difference: go to (11).

(6) Higher power microscopy, wiggling glare angle illumination:

(7) Characterize appearance of darkened band of toner:

(8) Dulled or discolored highlight pattern: go to (12).

(9) Dead black, no highlight pattern: go to (13).

(10) Laser printing first, writing second. Burnish glare and/or thin film glare.

(11) Uncertain; possible indication that pen skipped over toner without touching it or that ink was applied but ran off or soaked through leaving no visible trace. If writing is indeed embossed, absence of thermal gradient band from embossment sheltering indicates laser printing preceded the writing.

(12) Laser printing first, writing second. Ink film effect.

(13) Writing first, laser printing second. Thermal gradient mechanism in effect.

References

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Planty, Michael G. (1997). Determining the Relative Chronology of Intersecting Ballpoint Pen Lines and Laser Printed Document Marks – Linton Godown Revisited. *International Journal of Forensic Document Examiners,* Vol. 3, No. 1, pp. 31-34.