Cohesive Ink Failure in Thermal Transfer Printing

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Abstract

Thermal Transfer Ribbon (TTR) printing is a useful digital marking technology for printing on-demand bar code labels. Over the past decade, a number of advances have taken place with both the printing mechanism and media to enhance image performance in terms of print speed, image durability, print quality, resolution, and cost of ownership.

This technical paper investigates a printing defect referred to as “ink split”, a phenomenon that manifests itself under certain printing conditions. As part of this investigation, the TTR printing model is revisited. Empirical evidence of the ink split defect is reviewed. Conventional thermal transfer ink layer construction is described. A cohesive failure mode is described in terms of the printing model and includes a description of crack propagation that occurs within the ink structure during the printing process.

From this analysis we have found that complex ink formulations and multiple ink layer constructions in conjunction with high print speed have the potential to produce this ink split defect. The severity is influenced by temperature and nip pressure conditions. Furthermore, this defect can be reduced and eliminated by several different print system modifications.

Introduction

Thermal transfer ribbon printing is one of the most common, cost-effective, and reliable methods for printing on-demand variable information. This technology has gained wide acceptance in the printing of on-demand bar coded labels. The technology offers several benefits that include high print quality, durable images, and high printing speeds. This paper describes the ink split defect, reviews the ink transfer model, discusses ribbon construction and the print mechanism, and describes steps used to eliminate this defect.

Ink Split Defect

When printing with thermal transfer technology at high speeds on die cut labels, a printing defect can result that is called “ink split”. As implied by the name, the print defect appears as a partial transfer of ink from the thermal transfer ribbon to the target label. This defect occurs at the leading edge of a die cut label and will initiate at the start of the image and continue partially through the image. Figure 1 shows ink split in a UPC bar code printing in a non-rotated orientation at the leading edge of a label.

Figure 1. Ink Split Example

Figure 2. Spent Ribbon Film

As you can see, the black image contains a gray portion that is located on the first half of the bar code. On closer inspection this gray area appears to have reduced image density and gloss compared to the other region. Examination of the spent ribbon film shown in Figure 2 clearly shows a portion of the ink layer remaining with the ribbon.

A closer inspection of the failed image, under higher magnification in Figure 3, shows that a propagation pattern exists within the deposited ink. Note how the transition point appears to quickly taper off from a weak partial matrix into a solid image.

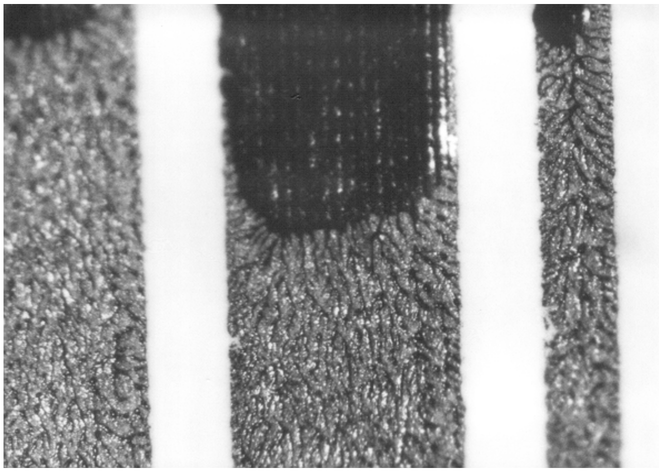

Figure 3. Propagation Pattern within Deposited Ink

Empirical evidence shows the severity of the defect is related to the mechanical platform, media, and printing conditions.

Ink Transfer Model

The method of ink transfer needs to be reviewed to understand the cause of ink split. Ink transfer is a two-step process. The first step is Ink Adhesion where the thermal transfer ribbon is brought into contact with the target receiver and exposed to high printing temperatures. The second step is Ribbon Separation. During this step, the media is transported to a location where the thermal transfer ribbon is peeled away from the target substrate leaving the desired image.

Step 1: Ink Adhesion

The level of adhesion is a function of heat, nip pressure, ink/label compatibility, and time. High print head temperature causes the heat-fusible ink to melt and adhere to the label surface at the printing nip. Under these temperatures the ink softens or melts and intimate contact is achieved with the target surface. From the high nip pressure at the print bead, ink is forced into the label surface by a wetting process resulting in adhesion. The two sources of adhesion are mechanical interlocking and/or physical bonding. As a result of the heating step, three forces exist that hold the thermal ribbon in contact with the receiver as shown in Figure 4. The magnitude of these forces will depend primarily on the temperature of the ink.

- F1 - Adhesional force between the ink and the PET film
- F2 - Cohesional force within the ink
- F3 - Adhesional force between ink and label surface

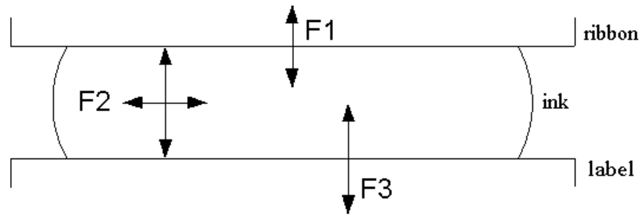

Figure 4. Forces at Ribbon/Label Interface

Step 2: Ribbon Separation

After the Ink Adhesion step, the combined components are transported to a separation point where the ribbon is peeled away leaving the desired image. The separation process causes the forces acting on the ink to compete against each other. This competition of forces is described by Akutsu *et al.*[1] Three possible separation modes can result during this ribbon separation process:

- Complete ink transfer: Adhesion separation of ink from PET film (F3 ≥ F2 > F1)
- No ink transfer: Adhesion separation of ink layer from target substrate (F1 ≥ F2 > F3)
- Incomplete ink transfer: Cohesive separation in ink layer (F1 ≥ F3 > F2)

When sufficient adhesion exists between the ink layer and receiver surface, separation is caused by a crack that initiates at the ink/receiver interface and will propagate in the ink layer. Depending on the strength of the forces, the propagation path will either continue to the ink/film interface or proceed through the ink layer in a cohesive failure mode. Potential separation paths are shown in Figure 5 as Path 1 & 2, respectively. Ultimately, the path of least resistance through the ink dictates the path of separation. The crack will continue until a change in the forces acting upon the ink occurs. For example, when the adhesion force at the ink/label interface is eliminated, the crack propagates back to this interface representing the end of a transferred image in this discrete location.

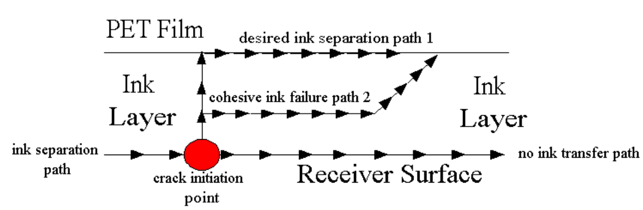

Figure 5. Separation Paths

Under the conditions of cohesive ink failure, the crack starts at the point of initiation and propagates through the ink layer but never reaches the PET/Ink interface. As described in the previous sections, this cohesive separation occurs in the ink when the forces meet the following condition; F1 ≥ F3 > F2.

Ribbon Construction and Print Mechanism

A review of thermal transfer ribbon construction and the printing mechanism is required before describing factors that can promote cohesive ink failure. The ink transfer model that is described in the previous section refers to a generic ribbon construction. In general, a ribbon consists of several coatings made to a 4.5 micron polyethylene terephthalate (PET) base film. One side of this film is coated with a “backcoat” that has antistatic and low friction properties. The primary purpose of this coating is to ensure good transport of the ribbon through the printer by preventing adhesion to the printhead.

On the other side of the base film is the ink. In actuality the ink side can consist of a number of coating layers where one is a pigmented ink layer. Along with this layer a number of additional layers can be present that will help with releasing the ink layer from the PET film or imparting enhanced durability to the transferred image. The pigmented layer on the ink side of the ribbon can consist of a number of ingredients including waxes, low molecular weight resin, additives, and pigment. Refer to Figure 6 for a cross section of a thermal transfer ribbon.

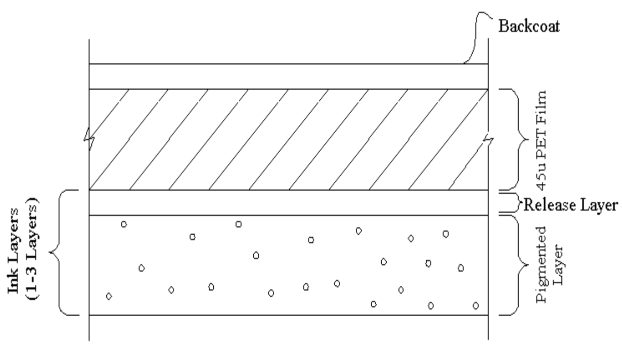

Figure 6. Cross-section view of conventional TTR

The basic print mechanism consists of a platen roller and print head. A receiver and ribbon are transported through the print mechanism to obtain a printed image. The quality of the printed image relative to the mechanical platform is ultimately affected by a balance between print head pressure and position relative to the platen roller. This balance is directly associated with the nip pressure. Nip pressure requirements vary depending on the receiver and ribbon formulation.

Resolution

Several factors influence the occurrence and severity of the ink split defect. These factors are related to both the ribbon design and print mechanism design.

1) Ribbon Design

There are three main ribbon factors that can influence the occurrence of ink split or cohesive failure. First, the ink is a non-homogeneous system that is typically comprised of components not completely compatible with each other. Ingredients include low melt temperature waxes, relatively low molecular weight resins, very low molecular weight additives (e.g., plasticizers, surfactants), and pigment such as carbon black. In a complex system the low molecular weight waxes and pigment offer low strength regions or additional interfaces that can allow the crack to propagate through the ink. Engineering an ink system that is more homogenous or using ingredients that are more compatible will reduce the tendency to cohesively fail.

Second, ink is exposed to high temperatures from the thermal printhead during the printing process. The temperature to which the ink is exposed to, depends on several factors such as print energy setting, thermal compensation, and image size. If we consider our ink as a polymeric system, it has been documented that the ink viscosity and the cohesive strength will decrease as temperature increases.[2] As a result, ink cohesive strength will decrease at high temperatures. Because of this, the selection of ingredients that have proper melt behavior is important to reducing cohesive failure.

Third, ribbons typically incorporate multiple layers as described earlier. A common construction for thermal transfer ribbons is the use of a release layer that is intended to allow the ink layer to transfer easily. With this type of construction, the interface of the release layer and pigmented layer can act as a preferred path for the crack to propagate. This is especially true when these layers have not mixed during the coating process and act as a third interface with weak adhesion. Another contributing factor is the incompatibility of the two layers that will leave pockets void of ink or primer. These voids will also promote the propagation of the separation crack. As a result, coating quality and coating layer compatibility are important to controlling the interface in which crack propagation will occur.

2) Print Mechanism Design

Empirically, the severity of ink split is found to be dependent on level of pressure at the printing nip. Evidence suggests that high nip pressure increases the magnitude of the adhesional forces at the ink interfaces and promotes cohesive ink failure. Several print mechanism variables can be altered to influence the level of pressure at the nip. In addition, other factors outside the print mechanism can be modified to influence nip pressure.

Ink split is impacted by the relationship of the mechanical platform, media, and printing conditions. The mechanical platform includes printhead position, platen hardness, and strip distance. The printhead position relative to the platen roller is directly associated with the nip pressure. Obtaining the optimum nip pressure and maintaining it at the print bead is critical for achieving ink transfer.

Nip pressure is greatest when the printhead's heater elements are positioned top dead center (TDC) to the platen roller. Moving the printhead beyond the TDC position will reduce the nip pressure. Pressure is specifically reduced at the heating elements on the print bead. Modifying the platen roller can also change pressure at the print bead. The platen is used to exert or receive pressure. The harder the platen the more pressure it exerts. A softer platen absorbs pressure. Decreasing platen hardness will subsequently decrease nip pressure. In both cases, reducing nip pressure decreases the incidence of ink split.

Another consideration relative to the mechanical platform is the strip distance. At the strip point the ribbon is peeled away from the receiver. The competing forces acting on the ink during the separation process are affected by the location of the strip point. The distance from the print bead to the strip point will dictate the magnitude of each force acting on the ribbon and will vary depending on the distance to the strip point. The greater the distance the cooler the ink is during separation.

Media factors include non-continuous label stock and label stock thickness. Ink split does not occur on continuous media where the nip pressure stays relatively constant compared to printing on media with gaps between labels. When printing on non-continuous labels, an abrupt change in pressure occurs as the print bead travels from the gap over the label. This abrupt change momentarily increases pressure at the print bead producing ink split. This behavior explains how the ink split defect occurs at the start of the label where the pressure has momentarily increased. The defect disappears as the pressure is dampened during the printing of the label. This condition is exaggerated with thicker labels because the thicker label stock produces greater pressure at the print bead consequently increasing the occurrence of ink split.

Printing conditions such as print location and print speed will impact the severity of the ink split defect. Simulating conditions present when printing on continuous label stock will reduce or eliminate ink split. Specifically, the further the start of print is from the leading edge of the label the less likely ink split will occur. Similarly, printing at a slower print speed will also allow time for the system to stabilize and reduce ink split.

Conclusion

As specified in the previous section, ink split is impacted by the thermal transfer ribbon design and mechanical platform design. Changing parameters under one or more of these categories will reduce or eliminate ink split:

Ribbon
- Homogenous ink system
- Compatible ink ingredients
- Proper melt behavior of ingredients
- Coating quality of ribbon layers
- Compatible ribbon layers

Mechanical Platform
- Move printhead away from TDC position relative to platen roller
- Decrease platen hardness
- Increase strip distance

Printing Conditions
- Place image back from leading edge of label
- Print at slower print speed

References

1. Eiichi Akutsu, Hiroh Soga, Shigehito Ando, Kazuo Maruyama; Analysis of Polymer Ink Transfer Phenomenon in Thermal Transfer Printing Technology, IS&T's 8th International Congress on Advances in Non-Impact Printing Technologies, 1992.
2. Ferdinand Rodriquez, Principles of Polymer Systems, Second Edition, Hemisphere Publishing Company, 1982

Biography

Tom Rogers (Presenter)

Tom is a Media R&D Manager with the Printer/Media Division of Intermec Technologies Corporation located in Fairfield, Ohio. Previously, Tom was an engineer in the Printer Engineering group with Intermec and a Product Development Manager with IIMAK. He is a graduate of the New Jersey Institute of Technology (BS CHE) and the University of Idaho (MS CHE). He is currently pursuing his MBA at Xavier University.

Kevin Conwell

Kevin is a Media R&D Engineer with the Printer/Media Division of Intermec Technologies Corporation located in Fairfield, Ohio. He is a graduate of Wright State University with a BS in Electrical Engineering. He has authored a number of patents pertaining to Bar Code media supplies. He has 16 years experience with thermal printers and media. His area of expertise is direct thermal and thermal transfer printing.

Kathy McCready

Kathy is a Printer R&D Engineer with the Printer/Media Division of Intermec Technologies Corporation located in Everett, Washington. She is a graduate of the University of Washington with a BS in Technical Communications. Previously, Kathy worked as a mechanical engineer in the Data Capture Engineering group. She has over 9 years experience in product development. Her area of expertise is the printer thermal interface.