A Thermal Printing Interferometer

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This report describes a dynamic monochromatic interferometer designed and built to look at the printing interface in a thermal printer during the image printing process. The apparatus was developed around a Kodak XLS 8600 printer, where the printhead was replaced by a transparent alumina rod, while the printer's paper and dye donor transport mechanisms were unaltered. The optical interference pattern that is observed within the printing nip provides a quantitative measure of the contact zone and spacings that exist within both, the donor lube to printhead and the donor dye to image receiver interfaces. The apparatus enables visual examination of the influence of donor and receiver surface characteristics on the contact within the printing nip. Further, it enables microscopic observation of particle transport through the nip and shows the impact of particle adherence to the printhead on interface separation.

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Introduction

The use of interferometry to quantify contact and measure separation in the interface between two complying or closely separated surfaces, with or without relative motion, is well established. It is routinely used in the field of magnetic recording to look at contact and the submicrometer spacing between recording heads and the recording medium. For magnetic hard disk recording, the characteristics of slider motion over the disk surface is commonly measured using interferometry.[1] In magnetic tape recording, the compliance between the tape and the recording head is studied extensively for linear tape recorders[2] and rotary videocassette recorder (VCR) type systems.[3]

The application of interferometry to examine a thermal printing nip has not been reported in the technical literature. Typical print heads are 200–250 mm wide, compared to magnetic tape heads with widths of, at most, 25 mm. Flatness of the relatively wide printhead is critical, since a uniform nip pressure is advantageous across the whole contact zone to avert undesirable printing artifacts. The thin film resistor print head has individual heater addressing. Thus, at the instant during printing of a typical image, numerous resistors in the print head are energized, while many more are not, depending on the optical density at the particular location in the image.[4]

The thermal printing interferometer must to be designed to operate at elevated temperatures, providing a unique technical challenge. For a dye-diffusion thermal printer, dye does not transfer at a reasonable rate at ambient conditions. There is a threshold activation temperature where the diffusivity of dye from the donor to the receiver begins to occur at a rate suitable for printing, and above which the diffusivity rate continues to rise with further increases of temperature.[5] The upper temperature for printing is limited by what the polymer sheets in the system can tolerate. The thermal printing system is designed to operate at elevated temperatures, and importantly the donor layer has a lubricant specifically designed to operate at these elevated printing temperatures.[4]

In interferometry studies, a member of the contact pair is required to be transparent to transmit light to the interface. In magnetic recording, depending on what is being studied, either the solid recording head can be replaced by a transparent glass structure of identical geometry, or the magnetic medium can be replaced by a transparent medium, for example Mylar. In a thermal printer, the only practical option is having a transparent print head, since dyes are opaque and implementing a transparent support roller did not seem feasible. Thus, the actual print head is replaced by a transparent structure having an identical geometry.

The Dynamic Thermal Printing Nip Interferometer

A commercially available Kodak XLS 8600 thermal printer was modified and used as the foundation on which to build the interferometer. To replicate the thermal print head structure and function, and to facilitate interferometry, a transparent alumina rod—through which light passes enabling the formation of nip interface separation induced optical interference fringes—is used. The following sections describe the structure surrounding the transparent rod and the modifications to the printer.

The "Transparent" Print Head. Figure 1 shows a cross-section of the interferometer, highlighting the active components, including the support roller, the image receiving paper, the donor, and the print head replacement. The transparent alumina rod, the heating wires (described in the next section), and ceramic insulators are all contained within a housing, which occupies the original print head location in the printer. Alumina was selected because it

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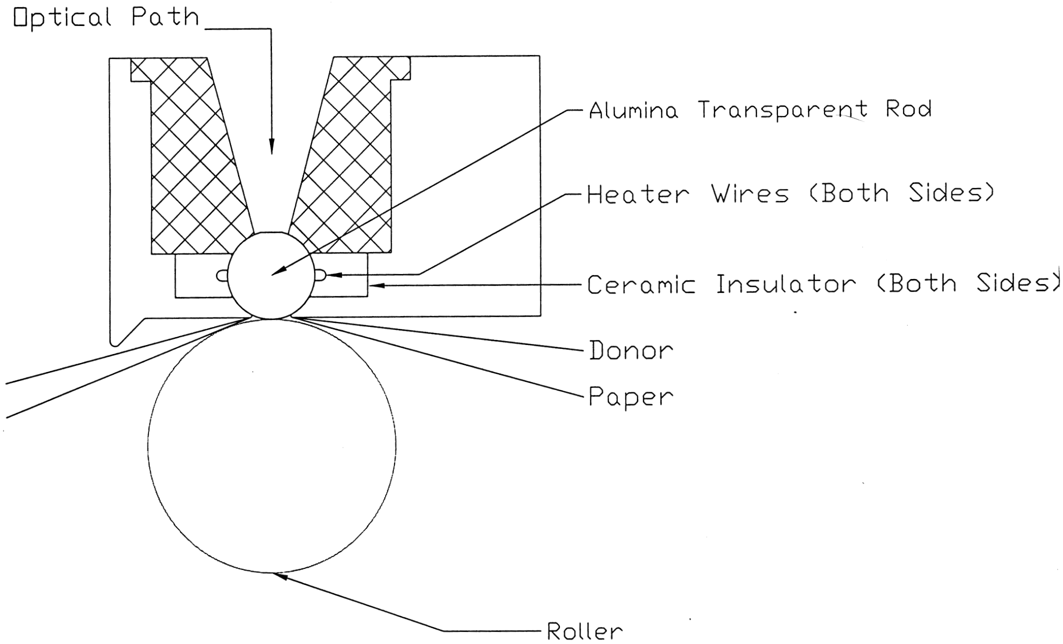

Figure 1. Cross-section of the assembly containing the transparent alumina rod, heater wires, and the optical path.

best resembles the print head bead protective layer material, and had good wear resistance and heat stability. The alumina rod has a diameter of 6.35 mm, equal to that of the print head bead. It protrudes 76 µm from the housing, emulating the print head bead height. It has an optical flat cut on the light impinging surface to minimize light dispersion.

Heating the "Transparent" Print Head. A pair of nichrome wires run parallel to the rod on both sides, and uniform heating of the rod is maintained by controlling the input power. The wires are held in contact with either side of the rod using ceramic (thermal and electrical) insulator pieces. The rod temperature is monitored by thermocouples, attached to the rod and housing in different locations along the length, that feed input to a temperature controller. A set of three fans mounted within the printer housing removes excess heat that is conducted to the rod housing by blowing air perpendicular to the alumina rod, enabling a rapid cool down of the rod.

Printing Nip Interferometry. A single-wavelength (546 nm) monochromatic light source, with a green filter, transmitted via a fiber optic cable, illuminates the printing nip interface. Light reflected back from two closely spaced surfaces interfere and the resulting interference fringes provide a measure of that spacing. Contract is represented by a dark fringe and as spacing in the interface increases from zero, the fringe gray-level intensity varies sinusoidally, alternating from dark to bright and back again. The first bright fringe or region of high-intensity light, adjacent to the contact zone in the interferogram, represents a spacing of a quarter wavelength, or 137 nm. As one moves farther from the contact zone, the next fringe is dark and represents a spacing of a half wavelength, or 273 nm. The sinusoidal variation in intensity continues, with each subsequent dark fringe, moving outward from the central contact zone, representing an additional half wavelength, or 273 nm, of spacing. The gray-level intensity variation within the contact zone is a measure of a separation range from 0 to 137 nm. The contact pressure increases with decreasing separation, depending on the contacting surface asperity height and distribution. Thus, from the interferogram, you can obtain a map of the contact zone and variations in spacing as one moves away from contact. For simple fringe patterns, software exists to translate the interferogram optical intensity to an actual separation map. This is a challange for software when the interferogram is a complex pattern. However, for this application, the trained eye can translate the interferogram to a spacing map quite easily.

The interferograms are captured with a charge-coupled device (CCD) and are displayed on a monitor, as well as stored in a computer-based image-grabbing device. The optics has a zoom in and out control along with a focus adjustment. The CCD camera is attached to a single-axis translating stage mounted on the frame of the thermal printer—above the rod housing. The interferometer focuses through the alumina rod onto *both* the rod to donor lube and the donor dye to receiver interfaces. A Kodak high-speed camera was used to capture the dynamics of the interface at normal printing speed, since it has the capability of capturing 1000 frames/s and storing 5.4 s of motion. It enabled playback of the dynamic fringe patterns at a much slower speed for a more careful analysis of the nip.

The housing has a long narrow rectangular opening to facilitate the optical path, enabling observation of the nip along the full 216 mm of contact. This is accomplished by placing the test bed on a translating stage, enabling any position in the nip to be monitored. The rod housing moves vertically on a manually controlled rack-and-pinion gear system.

Donor and Paper Transport. In addition to having the printhead completely removed and replaced by the rod housing, the Kodak XLS 8600 printer was further modified as follows. The entire electronics and control circuitry were disabled. Figure 2 shows a schematic of the overall test bed system, with a computer operated, motor con-

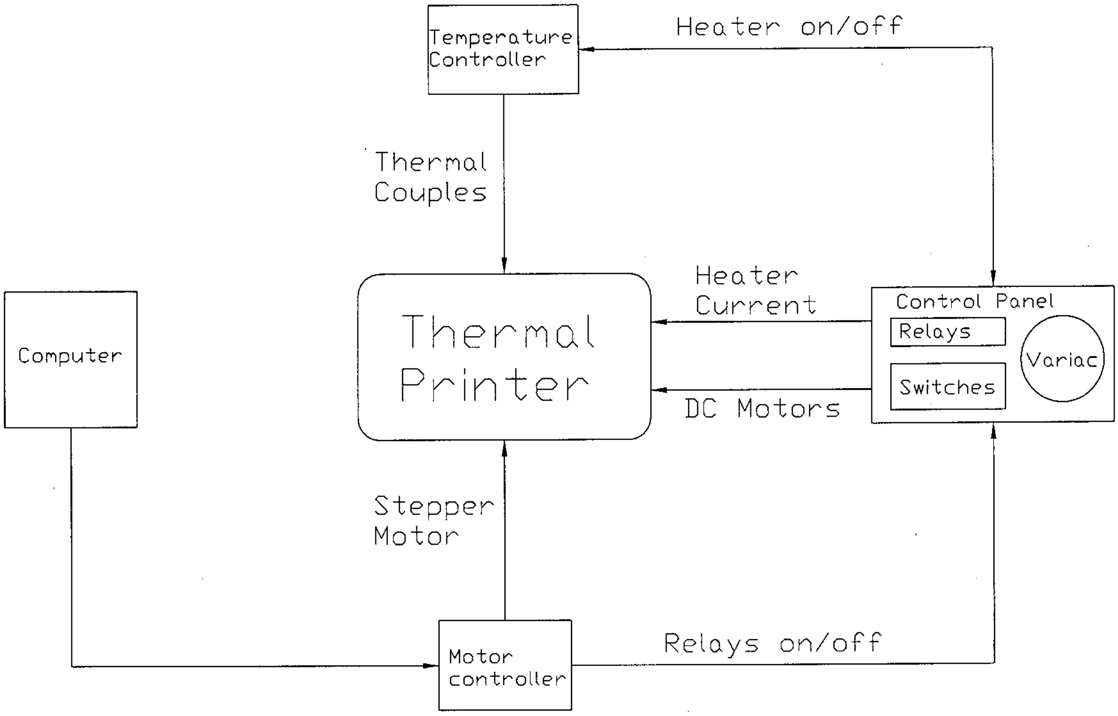

Figure 2. A schematic of the overall test bed system, with the computer-operated motor controller, the variac controlled current flow, and the omega temperature control.

troller for donor and receiver transport, and the variac-controlled current flow and omega temperature control for the rod. In the receiver, both donor transport and the pinch motors are externally computer controlled. The dye donor and receiver transport paths are not changed. The printer's four main dc motors were rewired for computer operation by a motor controller, or for manual control by switches on a control board. These four motors are the receiver loading motor, the donor "take-up" and "give" motors, and the pinch motor. The receiver transport motor is replaced by an accurately controlled stepper motor.

Programmed motor control sequences are executed as required. The sequences are broken up by operation; stepping motor or motion sequences, output sequences, and run sequences. Motion sequences control the motion of only the receiver transport stepper motor at various speeds. The output sequences operate the donor and pinch motors. Run sequences combine the motion and output sequences, giving a complete pass of the media and donor through the interface at a specified speed. The loading sequence turns on the media and donor motors, then runs the motion sequence after which the motor outputs are turned off. It also runs the stepper motor, which transports the media through the interface.

Control Board. The control board is the heart of the system. Aside from the motor controller, all the electrical connections are made through it. The temperature controller, thermal printer, variac, motor controller, digital multimeter, power supplies, cooling fans, and heaters plug into the board. The control board houses all the relays for the heaters, cooling fans, and the four motors as well as their control switches. The control switches are very important because they interact with the motor controller.

Temperature Controller. For temperature control in the printing nip, a two-input, two-output temperature control unit is used. The controller uses the "K" style thermocouple. There are a total of four thermocouples, one in the heater wire duct, two on the alumina rod, and one on the rod assembly housing. The set point temperature is the temperature you want the rod to achieve and the point you want the controller to hold, and is easily programmed. When the input temperature matches the set point temperature, the controller turns off the power. When the temperature drops below the set point, the controller again supplies power to the output.

Power Supply and Control. Several 12-V and one 24-V power supplies are used to furnish power directly to the thermal printer's four dc motors and to the cooling fans. The motors and fans require 12-V, and some of the coils in the relays operate at 24-V. A variac controls the amount of power supplied to the heaters in the thermal printer. The heater relay is turned on and off by the temperature controller.

Application, Results, and Discussion

As a precursor to the interferometry analysis, surface profile measurements were made of the donor and receiver surfaces using a vertical scanning interferometer, and these are shown in Fig. 3. The figure shows the roughness of the donor's dye and lube surfaces as well as the image receiving surfaces of both standard Kodak paper and transparency. Further, the figure clearly shows a significant roughness difference between the reflective paper receiver with a roughness of 250 nm, and the transparent plastic receiver with a roughness of 15 nm. The donor dye and lube surface roughness are comparable at 129 and 106 nm, respectively, but the asperity distributions are significantly different.

Numerous examinations of the printing nip interface for various donors and receivers were performed using the interferometer. Figure 4 shows a typical interferogram for a standard commercial Kodak donor and paper going

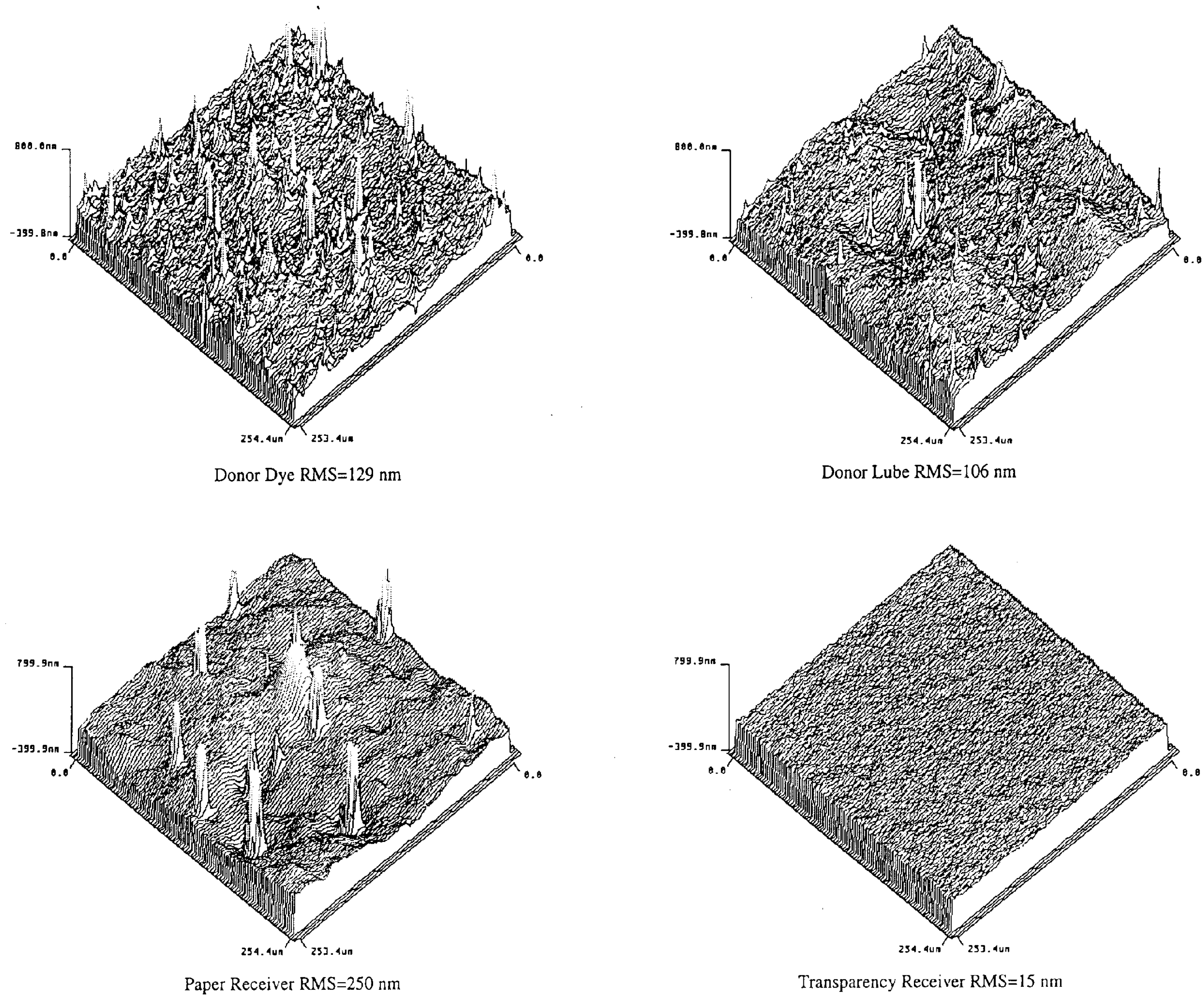

Figure 3. Surface profile measurements of the dye-containing front and the lube-containing back surfaces of donor and the image receiving surfaces of both paper and transparency made using a phase shift microXAM.

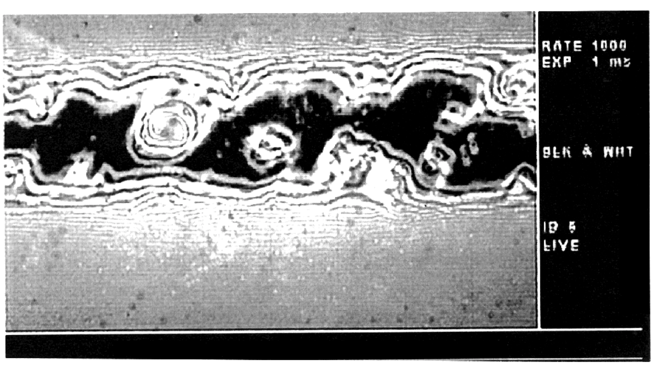

Figure 4. Interferogram showing the two contact surfaces of the printhead-to-donor lube interface and the donor dye-to-paper receiver interface.

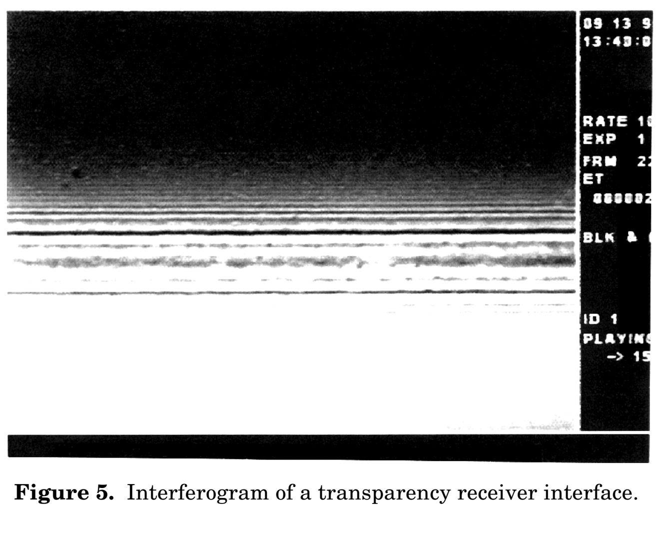

Figure 5. Interferogram of a transparency receiver interface.

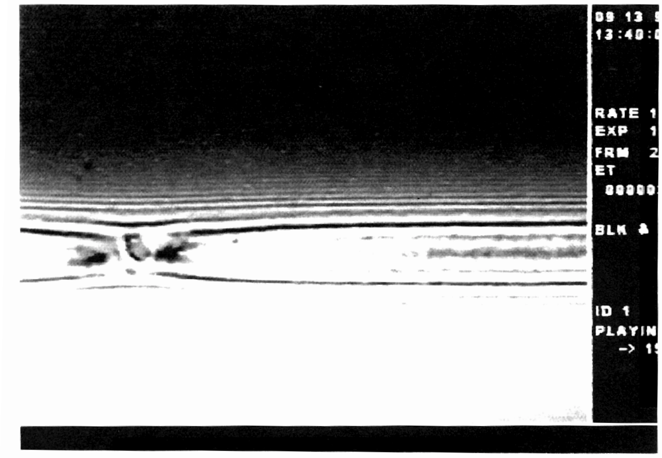

Figure 6. Static interferogram of a skin flake on the donor as it passes through the heated nip.

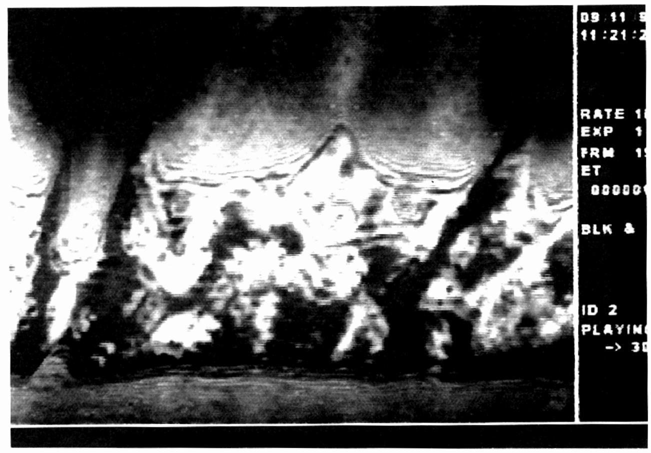

Figure 7. A static interferogram showing a glimpse of the movement of a wrinkle in the donor coming from the top of the image as it approaches, passes through, and exits the nip vicinity.

through the interface. The interferogram represents two contact surfaces:

- the print head-to-donor lube interface
- the donor dye-to-receiver interface

In the central region of the interferogram there are numerous "islands" of contact. These contact zones represent the contacts of the asperities, shown in Fig. 3, for the two contacting interfaces being compressed between the alumina rod and the support roller. The separation corresponding to the three or four dark fringes in the interferogram equate to a seperation of 819 to 1092 nm. In contrast, Fig. 5 shows a typical interferogram of the nip for a transparency receiver, where the fringe pattern shows a narrow central contact zone with parallel fringes spreading out representing the media and donor pulling away from the print head. This is consistent with the transparency surface profile, shown in Fig. 3. The paper receiver is much more compliant and for a given nip pressure, the resulting nip is much broader than for transparency. The interferometer can show the impact of nip load on the contact width for both receiving paper and transparency.

The interferometer is a particularly useful tool for looking at the dynamics of debris passing through the interface and the impact on spacing. Figure 6 illustrates a static glimpse of a piece of skin flake on the donor passing through the heated printing nip. The interferogram provides a measure of the height of the artifact—in this case, its height is between a first- and second-order dark fringe—probably around 410 nm in height. Under certain circumstances, this type of extraneous particle can stick to the head and cause a permanent image artifact.

The interferometer can also show the transient movement of a wrinkle in the donor as it approaches, passes through, and exits the printing nip. This is captured in Fig. 7, that shows a number of wrinkles coming into the nip from the top of the picture. The interferogram proved very useful in studying how donor tension and speed as well as print head bead temperature contributed to the formation of wrinkles.

Limitations of the initial interferometer design include the inability to vary the horizontal position of the apex of the rod relative to the apex of the support roller—an alignment critical in a thermal printer. In fact, the actual horizontal location of the contact postion of the rod to the media on the support roller varied with applied load to the assembly. This precluded a study of load on the nip. However, this limitation did not diminish the value of the unique information obtained on contact, pressure distribution, and separations and the dynamics of particle transport through the nip and adhesion to the rod. Second, the actual print head with its discrete resistors will differ in temperature distribution from the ideal uniform temperature distribution in our rod. This could be simulated by a slotted rod!

Conclusion

We have designed, built, and used the world's first thermal printing nip interferometer and described its salient features. It provides a quantitative and qualitative view of the printing nip during the printing process. It can look at the effect of numerous nip and material surface parameters on the interface conditions, as well as at the dynamics of donor wrinkles, debris transport, and adherence of particles to the printhead. Its microscope characteristic enables one to visually observe and replay in slow motion events internal to the nip. The interference fringes provide a quantitative measure of the separation induced within the two interfaces that are formed within the nip.

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