Impedance Technique for Assessing Indigo Blanket Electrical Properties

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Abstract

The HP Indigo process transfers liquid ink from the imaged photoreceptor to the media via a blanket, which possesses several key characteristics. Among these is sufficient conductivity to provide the electric field necessary to draw the charged ink from the photoreceptor. In this work we describe an impedance measurement technique to assess blankets. We find that features in the data can be assigned to individual layers within a blanket responsible for electrical transfer. The outer layer adjacent to the ink generally blocks charge within the contact nip time, suppressing possible ink discharge. The inner layer underneath readily allows charge through so that a sufficient field can be set up between the photoreceptor and blanket electrodes. The measurement also clarifies the role of temperature and the effect of absorbed imaging oil during the operation.

Introduction

The HP Indigo presses use a liquid electrophotographic (LEP) process to produce excellent print quality (PQ) [1,2]. One key element is the binary ink developer (BID) unit [3,4] which concentrates the ElectroInk® [5,6] to a paste-like consistency onto the developer roller. This densified ink facilitates rapid development onto the latent image on the photoreceptor (PIP), allowing the process speed to reach 2.15 m/s in the HP Indigo 7000 Series III press announced at Drupa08. The ink is then transferred to a soft blanket, another key to the PQ, before it is applied to the substrate. The blanket compliance ensures uniform transfer to even rough surfaces, enabling the Indigo press to produce high-quality prints over a wide variety of substrates.

The blanket takes the imaged ink electrostatically from the PIP and heats it to substantially remove the carrier fluid. This process transforms the remaining ink solids into a polymer film with characteristics of hot glue, ready to be pressed onto the substrate. The blanket must be mechanically tough while compliant and chemically compatible with all ink components. Electrically it must produce a field sufficient to pull the ink from the PIP surface but possess sufficient resistance to prevent significant charge movement through the interface to discharge the ink. In this paper we describe an impedance measurement technique to assess the electrical characteristics of blankets. We show that the data can be matched to the known structure of a typical Indigo-style blanket and used to ascertain the role of individual layers. Other significant information can be gleaned as well.

Blanket Structure

The typical structure of Indigo blankets is illustrated in Fig. 1. Above the conductive layer lie the electrically relevant layers of the blanket, a thinner outer layer and a thicker inner layer. During transfer all ink on the PIP is moved to the blanket. The blanket conductor is set to about 400 V above the photoreceptor discharge voltage, some distance above the minimum threshold for complete removal of ink. This voltage is dropped through the relevant blanket layers, the ink and the PIP.

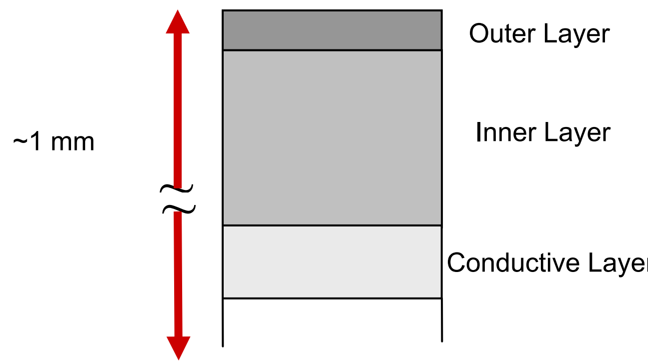

Figure 1. *A typical Indigo blanket has a sandwich structure ~1 mm thick. The electrically relevant part lies between the conductive layer and the outer surface. This consists of an inner and an outer layer.*

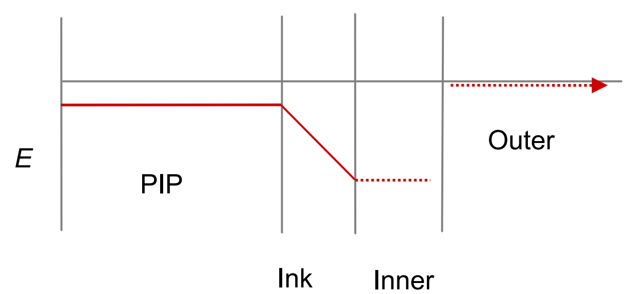

Figure 2. *The electric field between the PIP ground and the blanket conductor is shown for complete ink transfer to the blanket. Here the PIP discharge voltage is taken to be 0 with all PIP charges from the initial charging step neutralized. The ink charge density is assumed constant, making the field linear across the ink layer. The compensating charge from the erase step is assumed to be all driven back to the PIP ground. Together, this means the field is the same on the two sides of the PIP/ink interface if the dielectric constants of the two are the same (as shown). Blanket dielectric constant also assumed to be the same.*

Figure 2 shows a sketch of the electric field in the stack starting from the PIP ground using simplifying assumptions cited in the caption. The field at the PIP/ink interface is non-zero since the applied voltage is beyond the threshold. With an isolated ink layer equivalent to about -50 V (triangular part of the sketch), the PIP and ink takes up a non-negligible portion of the 400 V. If little or no voltage drops across the blanket, the field rejecting the ink from the PIP interface would be enhanced and help transfer –

unless charges bleed through and discharge the ink. So having at least the inner layer conduct would be immensely helpful. If not, the field at the ink/blanket interface would likely cause the drop across the blanket to be too large for transfer.

Experimental Technique

The impedance measurements were obtained using a Solartron 1280B Electrochemical Test Unit. This instrument operates from 1 mHz to 20 kHz, a frequency range that includes the portion useful for LEP-related studies. Typical high-end LCR instruments for electronics extend to multi-MHz but are limited to 20 Hz or more on the other side, a bit too high. For a blanket, two specific times are relevant. The first is the transfer nip time. Depending on how quickly the field sets up, the relevant frequency is somewhere around several hundred Hz. The second is the repeat period for the blanket, roughly 400 ms. Blanket charges are needed to recombine with whatever is left behind by the melted ink after transfer to the substrate. Otherwise, there would likely be voltage buildup that would eventually turn off the transfers. The relevant frequency here is probably several Hz. In our tests we measured from 1 Hz to 10 kHz, sufficient to get below and above the two key frequencies without taking too long to get the result.

Electrical contact to outside of the blanket is made using a 25 mm x 43 mm polished Al block. The conductive layer forms the other electrode. Although direct connection to the conductive layer is possible with some effort, we simplified the process by using an identical second block adjacent to the first. The signal goes through the two blocks via the conductive layer, which thus serves as the connecting wire. So the measured impedance Z is twice that of the blanket itself. We account for this by inputting half the electrode size in the Solartron. This double electrode arrangement allows very rapid changing of the blanket samples. Heating the blanket can also be done quite easily without worry about stray wires, something necessary for meaningful results since the blanket is operated ~ 100 C during printing.

A sketch of the measurement setup is shown in Fig. 3. The blanket is first cut oversized and adhered to the 51 mm x 117 mm heater block, then trimmed with a blade at the periphery of the block. Two 3.1 mm diameter 60 W cartridge heaters and a J-type thermocouple slip into holes in the block. A Teflon® slab matching the heater block in dimensions is placed underneath. This stack is covered by a Teflon® frame, which has an opening just big enough for the electrode assembly to slip in. The assembly consists of an open 38 mm x 107 mm x 27 mm Pomona Al box, the electrodes, and a Teflon® separator that goes between the electrodes and the box. The relative positions of the various components are indicated in Fig. 3 with all the Teflon® parts left out for clarity. The heater block, the blankets and the electrodes are surrounded by Teflon® throughout, except for a small portion of the box periphery that sticks in. Thus when the block is heated, the blanket temperature is expected to be close to that of the thermocouple very close by.

With all parts assembled and in place, the measurements for given parameters with one blanket were done in a single sitting starting from the lowest temperature. The results were obtained at room temperature (RT), 44 C, 70 C and 100 C in that order. With each increase in temperature, the assembly was allowed to equilibrate before activating the Solartron.

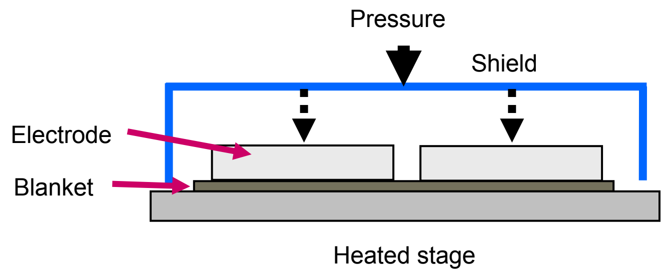

Figure. 3. *The impedance measurements were obtained using two Al electrodes squeezed against the blanket. The blanket conductive layer serves as the intervening electrodes as well as the electrical connection between the two sides. The pressure is applied by a pneumatic cylinder against the shield. The electrodes are attached to the shield using nylon screws with a Teflon® separator (not shown) in between.*

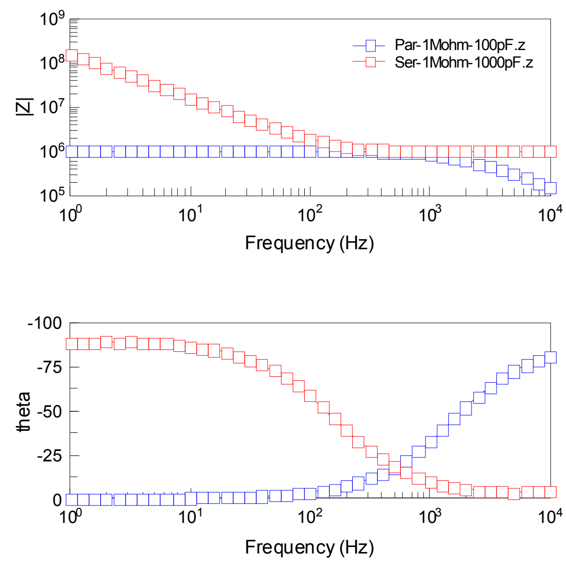

***Figure 4**. Impedance results for 1 $M\Omega$ resistor in parallel with 100 pF capacitor (blue) and in series with 1000 pF capacitor (red). The higher impedance component at a given f dominates the series, while the lower on dominates the parallel.*

Results

The impedance results are more readily understood if we first examine those for well known electrical components. Figure 4 shows the magnitude of the impedance |Z| and the phase angle θ as a function of frequency f for a resistor and capacitor in series and parallel. The graph is log-log for |Z| and semi-log for θ. A resistor impedance is just Z = R where R is the resistance. For a capacitor, Z = 1/iωC where ω is 2πf and C the capacitance. The 1/i gives the capacitance a phase of -90º while the resistor has a 0º angle.

Some features are immediately evident. A resistor produces a horizontal line in |Z| which reflects its value and horizontal line in θ corresponding to 0º. A capacitor |Z| gives a straight line which falls one decade for one in f with a –90º phase angle. For a series resistor-capacitor (red), the higher |Z| part at a given f dominates.

Hence the capacitor behavior is most evident at low f. Indeed its value, 1000 pF can be checked against the equation at 1 Hz. Here $1/2\pi fC$ = 1.6E8 Ω, fairly close to that seen in Fig. 4. For the parallel resistor-capacitor (blue), the lower |Z| component controls the results. Between the two extremes in frequency is a transition zone. These parallel/series combinations of resistor and capacitor turn out to be important for understanding blankets.

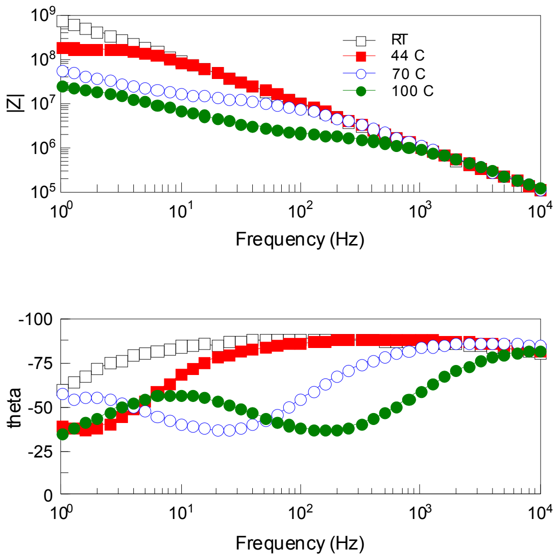

Figure 5. The impedance results for blanket at room temperature (RT), 44 C, 70 C and 100 C. At RT, the blanket looks almost like a capacitor. As temperature increases, some resistive features can be seen. By 100 C, the two distinct layers in the blanket structure become quite evident.

Figure 5 shows the impedance results for a blanket that generally resembles some used for Indigo presses. At RT, |Z| looks very much like a capacitor, falling about a decade per decade increase in f. The phase angle is close to -90º except approaching small f, suggesting the start of some charge movement. Since the blanket is not designed to be a capacitor, such leakage is not surprising. As the temperature is increased, current flow becomes stronger with the two-hump pattern in θ emerging fully by 100 C. Comparing Fig. 5 with Fig. 4, we conclude that the blanket appears to be similar to a parallel resistor-capacitor in series with another. This is the most obvious interpretation, assuming that the lower f branch corresponds to the thinner outer layer and the higher f one to the total capacitance above the conductive layer before any charge leakage, which shows up as the frequency decreases in a parallel resistor-capacitor (Fig. 4, blue).

With the electrode effective area inserted, the Solartron gives |Z| per unit area implicitly. These results are shown in Fig. 5 and beyond. Using gauss's law in a 1-d approximation and CV = Q, we obtain

$$C = \varepsilon\varepsilon_0 A/d \tag{1}$$

where ε is the relative dielectric constant, ε_0, the permittivity of free space, A the area and d the thickness. Assigning capacitance to the high f branch is not straightforward due to interference from the two leaking currents. Nevertheless, we can roughly project the 100 C |Z| to be 1.0 E5 at ~800 Hz, making C ≈ 2.0E3 pF. Using Eq. 1, the dielectric thickness d/ε is found to ≈ 0.4 μm. The capacitance across the two layers is about 130 pF using |Z| = 1.2E5 at 1.0E4 Hz. For series C_{outer} and C_{inner}, total C is given by

$$1/C = 1/C_{outer} + 1/C_{inner}. \tag{2}$$

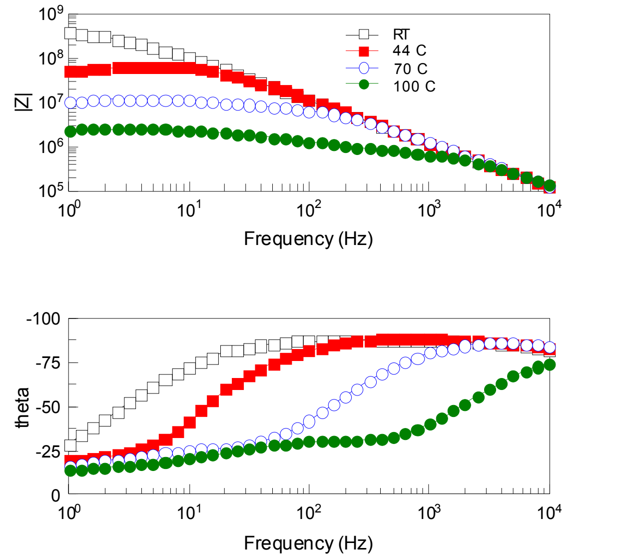

Figure 6. Impedance spectra for blanket with surface soaked in water, then wiped off. Note that for 100 C, |Z| remains unchanged at 10 kHz but is much lower at low frequency.

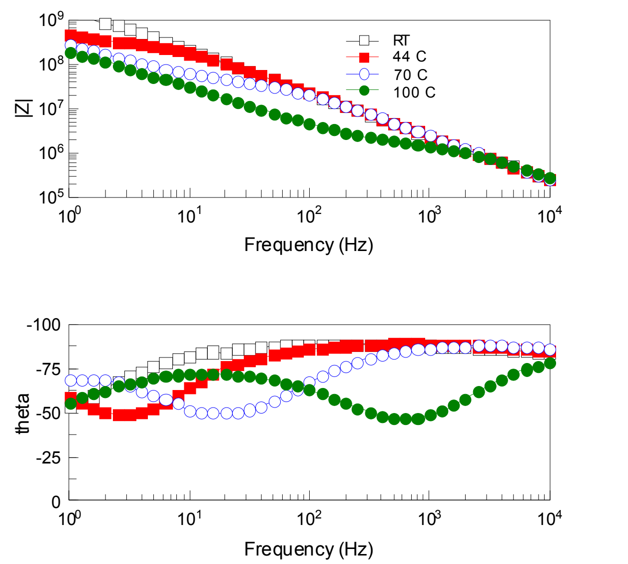

Figure 7. Impedance spectra for blanket with surface soaked in oil, then wiped off. The trends are similar to those in Fig. 5. But |Z| has shifted higher at 10 kHz and even more at low f, suggesting that oil has significantly penetrated the material above the conductive layer.

This is the situation at high f before either resistance becomes important. The equation can be solved for C_{inner} to determine d/ε, which we find to be ~ 6 μm. This is not negligible relative to the dielectric thickness of the ink [4].

If this blanket transfers well, it would likely due to conductivity through the inner layer, which is noticeable below f ≈ 1 kHz in Fig. 5. By 200 Hz, the inner layer resistance is probably already approaching its asymptotic value, which looks to be in the mid MΩ range, low enough for the needed charges to reach the back of the inner layer. The inner layer itself starts to conduct by 10 Hz. Although its asymptotic conductivity appears to be > 1E7, the time available for the charge to move is > 100 ms, significantly longer than the time to set up the transfer field. Hence even this higher resistance should be enough to bleed off any ink charge left behind.

We had assigned the lower f branch of the resistor-capacitor pair to the outer layer. To check this hypothesis, the blanket was covered with water and then wiped off. Figure 6 shows that the overall stack |Z| was not significantly impacted by comparing it with Fig. 5 at 10 kHz. The low f capacitance, on the other hand, has nearly collapsed with the material essentially conducting. This result is consistent with this low f branch being assigned to the outermost layer. The water had enough penetration to short it out. The phase angle at low f dropped to the -25º range, which is still some distance from the 0º for a normal resistive material. This suggests that the charge transport mechanism is more complicated than the simple leaky capacitor model we had envisioned.

In normal operation the blanket is in constant contact with imaging oil, the carrier fluid for the ink solids. This oil can be absorbed into the blanket. To assess its effect on electrical characteristics, oil was place on a room-temperature blanket, allowed to soak in, and subsequently wiped off. Undoubtedly a significant amount of oil remained and could not escape once the electrode assembly and Teflon® heat shield were put in place. Hence the results shown in Fig. 7 represent a rather extreme upper bound condition since oil can leave the heated blanket during operation.

On the low f side, the projected |Z| appears to be around 1.0E5 Ω at 5.0E3 Hz. This increases the dielectric thickness to > 5 μm, several times the sub-μm value for the oil-free standard blanket. This could be due to intense swelling of the blanket from the oil or just from some surface oil trapped by the electrodes, which increases the measured thickness. The dielectric constant could also be affected by the oil value, somewhere around 2.5. The inner layer may also have absorbed oil since its dielectric thickness nearly doubling to about 22 μm.

The asymptotic resistivity for the high f branch of the resistor-capacitor at 100 C appears to be roughly twice as large with the oil. This is probably not big enough to delay sufficient charges from reaching the back of the inner layer. The voltage, however, is dropped over the thickened inner layer thereby decreasing the available field for transfer. For actual press operation, the oil retained in the blanket is likely much lower. Hence the field decrease is probably nowhere near that suggested by Fig. 7.

Conclusions

In this work we showed that impedance measurements can be used to assess the electrical characteristics of blankets that generally resemble some used for Indigo presses. For the one tested, two distinct layers can be identified with their physical counterparts. Each can be considered similar to a leaky capacitor that can be modeled as a parallel resistor-capacitor pair. The impedance spectra can provide at a glance the likelihood that a particular blanket construction would work electrically, as well as the effect of such agents as imaging oil. Of course, many other properties play a role in whether a particular blanket type is useful for transfer. But no blanket can work without meeting electrical requirements. This impedance technique is one way to determine where the changes may have to be made.

Acknowledgments

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Author Biography

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