Stay Ahead of Static Problems in Film Conveyance

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ABSTRACT

Demands for static control in film conveyance are increasing because products are more complex and sensitive to static discharges. Four keys to staying ahead of static problems in web conveyance are:

1. BASELINE: Collect and document baseline electrostatic fieldmeter and non-contacting electrostatic voltmeter measurements. Use these measurements to identify sources of static when problem occur.

2. VERIFY STATIC DISSIPATORS: Verify that static dissipaters (ionizers, tinsel, etc.) are functioning properly.

3. TRACK ROLLER RESISTIVITY: Track the resistivity of polymer covered rollers.

4. MONITOR STATIC ON INCOMING AND OUTGOING MATERIAL: Monitor the static on incoming material from the unwinding stock roll and product near the winder.

The implementation of these four recommendations for a typical coating operation is presented.

I. INTRODUCTION

Requirements for static control in roll-to-roll manufacturing operations are becoming more demanding as film based products become more complex. Multi-layered films formed by coextrusion and lamination have engineered surfaces that are sensitive to static charge and electrical discharges. Biologically sensitive coatings for clinical diagnostic products and for a new generation of sensors will require excellent static control. Products on flexible film with integrated electronics such as RFIDs bring ESD sensitivity to roll-to-roll manufacturing. And, printed electronics on flexible films using electrically active coatings will be sensitivity to static charge.

Good static control is often achieved during the accreditation of a new operation or after solving a costly static problem. This is a prime opportunity to prevent most future static issues and to prepare to efficiently solve the few issues that will occur.

The four keys to staying ahead of static problems are presented for a coating operation.

II. ELECTROSTATIC MEASUREMENTS

Electrostatic charge separates when two chemically dissimilar materials touch and separate. Charge accumulates on the surface of insulating films as they are conveyed through a coating operation. When obtaining baseline static data, three instruments are commonly used. An electrostatic fieldmeter is used to measure the electrostatic field in the immediate vicinity of the film or a winding roll. Non-contacting electrostatic voltmeter is used to measure the electric potential of the film when it is wrapped on an idler roller. And, a megohmmeter is used to measure the electrical resistivity of polymer covered rollers.

With measurements from these three instruments, the static charge density on the film surface can be monitored and the electrical performance of key rollers can be tracked with time.

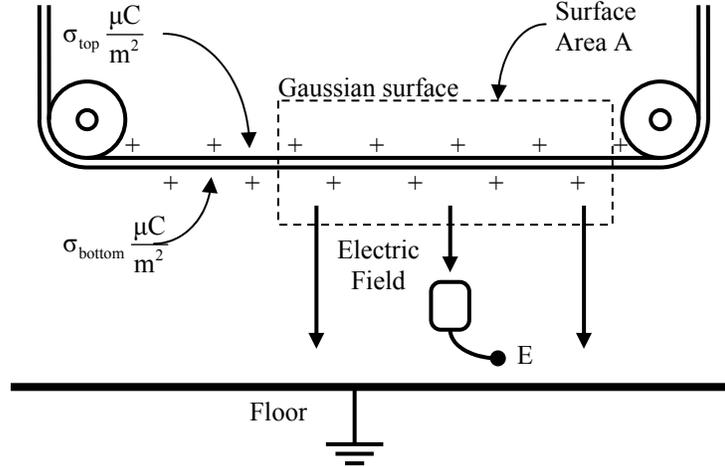## A.　　Measure Static Charge Using An Electrostatic Fieldmeter

Figure 1:　The film on this span between two idler rollers has charge density σ_{top} on the upper surface and σ_{bottom} on the lower surface. The electric field between the film and the floor is uniform because the film is parallel to the floor. The charge density is estimated by measuring the electric field and applying Gauss' Law.

As illustrated in Figure 1, the source of the electric field in the vicinity of a charged film is the sum of the charges on the top and bottom surfaces of an insulating film.

The relationship between the electrical charge enclosed within a control volume and the electric field that penetrates the surface (Gaussian surface) of the volume is Gauss' Law given in (1).

$$\oiint \varepsilon_0 \vec{E} \cdot d\vec{s} = q_{enclosed} = \oiint \left(\sigma_{top} + \sigma_{bottom} \right) da \tag{1}$$

TABLE 1: Electrostatic quantities in Gauss' Law

da	m^2	area element of the film
ε_0	Farads/m	permittivity of free space, physical constant (8.854 pF/m)
E	V/m	electric field
$q_{enclosed}$	Coulombs (C)	charge enclosed by Gaussian surface
σ_{bottom}	C/m^2	charge density on the bottom surface of the film
σ_{top}	C/m^2	charge density on the top surface of the film
ds	m^2	surface element of the Gaussian surface

For the geometry in Figure 1, Gauss' law is readily evaluated resulting in (2).

$$\sigma_{top} + \sigma_{bottom} = \varepsilon_0 E$$

$$\left(\sigma_{top} + \sigma_{bottom}\right)\left[\frac{\mu C}{m^2}\right] \approx 1.0 E\left[\frac{KV}{cm}\right] \qquad : \text{Film span parallel to floor} \qquad (2)$$

The sum of the charge densities on both surfaces of the insulating film is estimated by (2) using the electric fieldmeter measurements. The electric field changes with geometry as well as with charge density. In the more general case where a fieldmeter is used to measure the electric field on a span of web that is isolated (not adjacent to the floor), the sum of the charge densities is roughly estimated by (3).

$$\sigma_{top} + \sigma_{bottom} \approx \frac{\varepsilon_0 E}{3}$$

$$\left(\sigma_{top} + \sigma_{bottom}\right)\left[\frac{\mu C}{m^2}\right] \approx \frac{E}{3}\left[\frac{KV}{cm}\right] \qquad : \text{ Isolated film span away from floor} \qquad (3)$$

The estimated surface charge density on a film with an electric field of 3 KV/cm is 1 $\mu C/m^2$. Electric fieldmeter measurements are used to estimate total charge on the film (sum of the charge density on both front and back film surfaces) over a relatively large area (~1 meter diameter circle) of a film.

Electrostatic fieldmeter readings can be made using a hand-held meter that is convenient and easy to use. Electrostatic fieldmeters are the workhorse for quick diagnostic work.

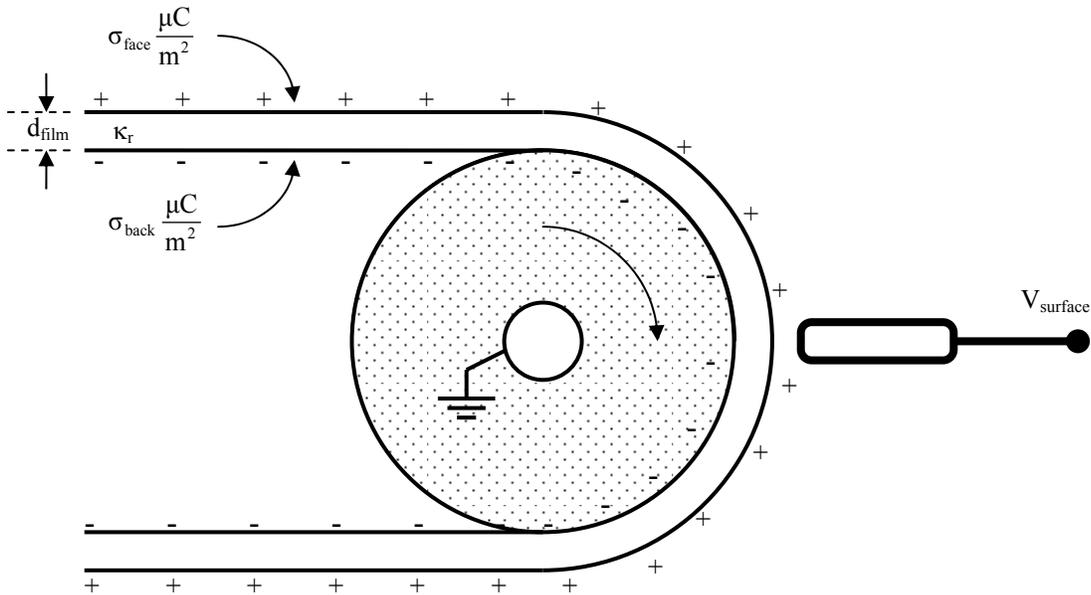**B.   Measure Surface Potential Using A Non-contacting Electrostatic Voltmeter**

Figure 2:   Charged film is wrapped around a smooth, metal idler roller. The non-contacting electrostatic voltmeter measures only the charge density σ_{face} on the exposed face side of the film

A non-contacting electrostatic voltmeter measures the electric potential of a nearby surface. When the film is wrapped around a grounded metal idler roller, the geometry is well defined and the surface potential is directly proportional to the charge density on the exposed surface. In the geometry illustrated in Figure 2, an electrostatic voltmeter measures surface charge density with high spatial resolution.

The electric potential of the film surface is determined by the surface charge density and capacitance to the metal idler roller as in (4).

$$V_{surface} = \frac{\sigma_{exposed}A}{C_{film}} = \frac{\sigma_{exposed}d_{film}}{\varepsilon_0 \kappa_r} \tag{4}$$

The charge density on the exposed surface of a film over an idler roll is estimated in (5) from the surface potential measured using a non-contacting electrostatic voltmeter.

$$\sigma_{exposed} = \left(\frac{\varepsilon_0 \kappa_r}{d_{film}}\right)V_{surface}$$

$$\sigma_{exposed}\left[\frac{\mu C}{m^2}\right] \approx 20\frac{V_{surface}[V]}{d_{film}[\mu m]} \tag{5}$$

Assuming that the relative dielectric constant of the film is 2, which is typical for polymers, the estimated surface charge density on a 10μm thick film with a surface potential of 10V is 20 μC/m^2.

Non-contacting electrostatic voltmeters require brackets to mount probes for measurement. The probes are somewhat delicate and require careful handling. For these reasons, voltmeter readings require advanced planning including scheduling machine time for set-up.

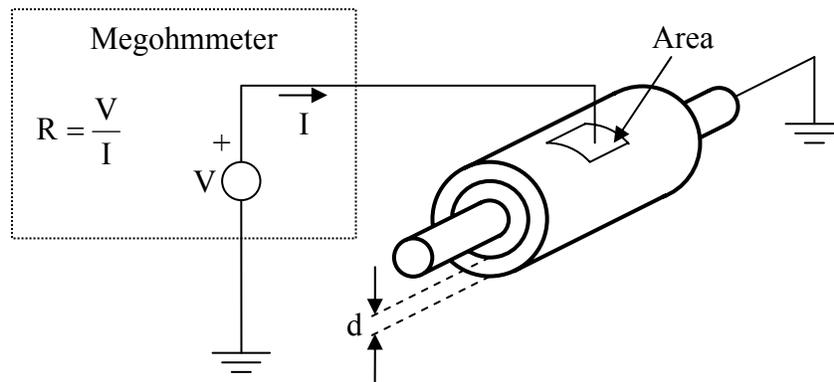### C.   Measure Roller Resistivity Using a Megohmmeter

Figure 3:   The resistivity of the polymer covering on a roller is measured using a megohmmeter and a flexible electrode with area A.

A megohmmeter or electrical insulation tester is an instrument that measures resistance. An internal power supply provides a voltage V on the output, the instrument monitors the output current I, and reports the ratio of V to I as resistance R. With an output voltage V in the range 500–5000V, the megohmmeter can measure resistances in the range 2–20 TΩ ($1T\Omega = 10^{+12}\Omega$). Knowing the area A of

the flexible electrode and the thickness d of the polymer covering of the roller, the resistivity ρ is calculated in (6).

$$\rho = R\left(\frac{A}{d}\right) \tag{6}$$

The units of resistivity ρ are Ω-m or Ω-cm.

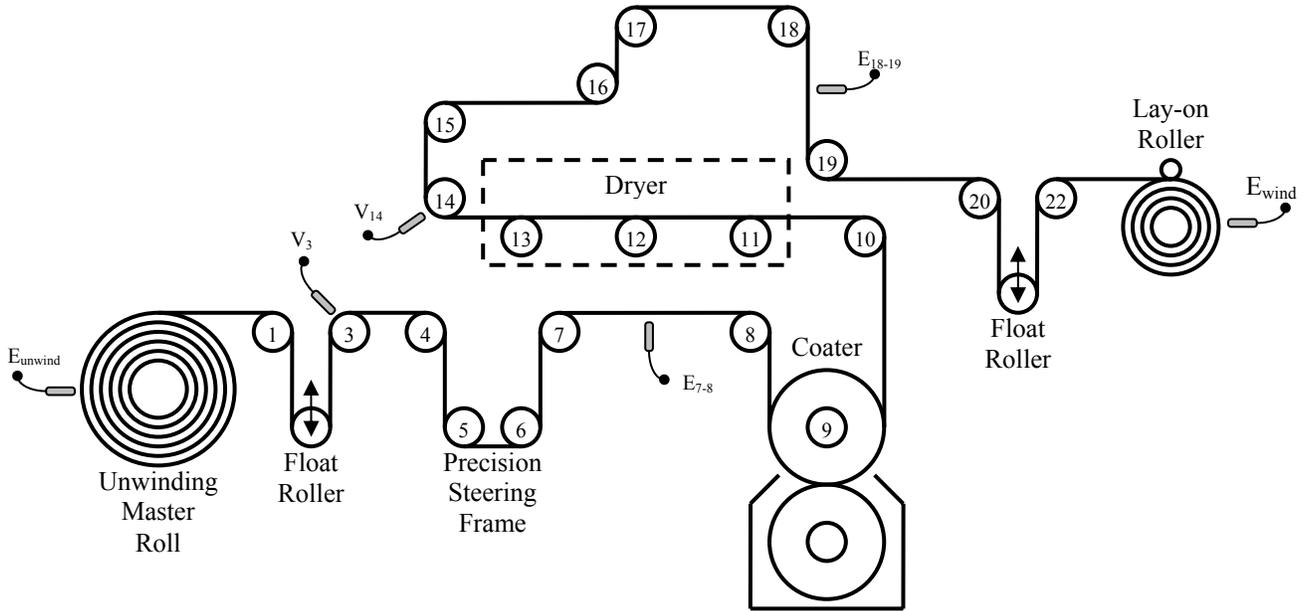## III.   CASE STUDY: COATING OPERATION

Figure 4:   For this coater, locations for six baseline electrostatic measurements are identified; four using a fieldmeter and two using a non-contacting voltmeter.

TABLE 2: Baseline Electrostatic Measurements

	Measurement	Units	Comments
1	E_{unwind}	$\frac{KV}{cm}$	The electric field near the unwinding stockroll helps verify the quality of incoming material.
2	V_3	V	The surface potential of the film near the unwind help verify the quality of incoming material.
3	E_{7-8}	$\frac{KV}{cm}$	The electric field just upstream of the coater is a key, baseline measurement. For solvent coaters, this is an important safety measurement.
4	V_{14}	V	The surface potential of the film exiting the dryer is a key, baseline measurements.
5	E_{18-19}	$\frac{KV}{cm}$	The electric field near the winder helps verify the quality of wound product.
6	E_{wind}	$\frac{KV}{cm}$	The electric field near the winding stockroll helps verify the quality of wound product.

A. Baseline Measurements

Figure 4 is the film thread-up diagram for a conceptual aqueous or solvent coater. A float roller controls the unwinding tension, a steering frame is just upstream of the coater, and a float roller controls the winding tension. The winder uses a lay-on roller to improve wound roll integrity. The locations for six baseline measurements needed to characterize the static performance of this coater are summarized in Table 2.

1. E_{unwind} – The electric field near the unwinding stockroll is taken manually using a handheld electrostatic fieldmeter because diameter of the stockroll changes as film unwinds. Readings are taken either at the center of the film or on the sidewall of the unwinding roll. Either location or both locations are commonly used for baseline measurements. Document the location used and be consistent. The electric field near the unwinding stockroll helps to verify the quality of incoming material by insuring that the level of static charge is low.

2. V_3 – The sensor used to measure the surface potential of the film near the unwind is usually permanently mounted and is also used to monitor incoming material. The sensor is usually located at the center of the film though additional sensors are sometimes added to monitor the surface potential near the edges of the film.

3. E_{7-8} – The sensor used to measure the electric field just upstream of the coater is usually permanently mounted and located at the center of the film. The sensor should be located in the center of the film midway between idler rollers. Keeping the electric field low on the film helps insure the uniformity of the coating. For solvent coating operations, it is very important to prevent static discharges (sparks) in the coater by verifying that the static charge on the film is low.

4. V_{14} – The sensor used to measure the surface potential of the film at the exit of the dryer is usually permanently mounted and is also used to monitor outgoing material. The sensor is usually located at the center of the film though additional sensors are sometimes added to monitor the surface potential near the edges of the film.

5. E_{18-19} – The sensor used to measure the electric field near the winding stockroll can be either permanently mounted or handheld. Readings are taken either at the center of the film on a free span midway between idler rollers. or on the sidewall of the unwinding roll. For handheld readings, document the location used and be consistent. The electric field near the winding stockroll helps to verify the quality of outgoing material by insuring that the level of static charge is low.

6. E_{wind} – The electric field near the winding stockroll is taken manually using a handheld electrostatic fieldmeter because diameter of the stockroll changes as film winds. Readings are taken either at the center of the film or on the sidewall of the unwinding roll. Either location or both locations are commonly used for baseline measurements. Document the location used and be consistent. The electric field near the winding stockroll helps to verify the quality of outgoing material by insuring that the level of static charge is low.

B. Verify Static Dissipaters (ionizers, tinsel, etc.)

The performance of static dissipaters such as active ionizers or passive tinsel should be verified periodically. While ionizers are now commercially available that provide an output to verify operation,

it is valuable to have an independent, manual verification procedure. Table 3 summarizes a simple procedure illustrated in Figure 5.
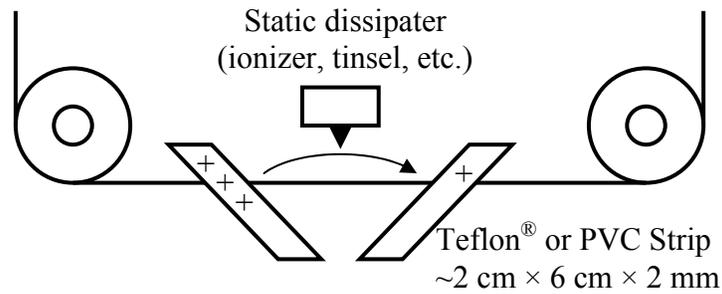

Figure 5: Static dissipater performance is verified by exposing a charged, insulating strip to the output and measuring charge dissipation efficiency with a handheld fieldmeter or a charge meter.

TABLE 3: Static Dissipater Verification Procedure

	Action	Comments
1	Charge insulating strip.	Charge a strip of Teflon® or PVC that is approximately 2cm × 6cm × 2mm by rubbing it against human hair, human skin, or a latex glove.
2	Measure initial charge.	Use an electrostatic fieldmeter or a charge meter to measure the charged, insulating strip. The field should exceed about ±10 KV/cm or ±10 nC.
3	Expose strip.	Expose the charged portion of the insulating strip to the ionizer output by pass it in front of the ionizer. The exposure time should be about 0.5S.
4	Measure final charge.	Use an electrostatic fieldmeter or a charge meter to measure the charged, insulating strip. If the ionizer is operating normally, the reading should be substantially lower.
5	Calculate dissipation efficiency	$\text{Dissipation Efficiency} = 100\% \times \dfrac{(\text{Initial Reading}) - (\text{Final Reading})}{\text{Initial Reading}}$

For example, if the initial reading on a Teflon® strip is −10 KV/cm and the final reading is −1 KV/cm, the dissipation efficiency is 90%. The dissipation efficiency of an ionizer operating normally should exceed 70%.

C.   Track Roller Resistivity

Polymer covered rollers such as nip rollers, drive rollers or cleaning rollers are common sources of static. Many of these rollers are specifically formulated to produce low levels of static and have good performance when they are clean. Over time, rollers become contaminated or glazed and their static performance degrades. Tracking roller resistivity over time is an effective way to monitor the condition of polymer covered rollers.

The technique is illustrated in Figure 3 and summarized in Table 4. For example, if the resistance measure 500 GΩ on a roller with a 1 cm polymer covering, the resistivity is $1.2 \times 10^{+13}$ Ω-cm. When the resistivity increases too much, perhaps by 5X, the roller should be cleaned or the surface ground to restore the original resistivity. The appropriate threshold that triggers roller maintenance should be determined for each roller using a control chart.

TABLE 4: Roller Resistivity Measurement

	Action	Comments
1	Fix flexible electrode to roller surface.	Place a flexible electrode such as a 4cm × 6cm × 1mm piece of silicone rubber filled with nickel/graphite particles on the surface of the roller and fix it in place using cable ties.
2	Clip ground lead of megohmmeter to roller shaft.	Attach the ground lead of a megohmmeter to the roller shaft. This may be done while the roller is installed in the coater as long as the machine is not running.
3	Touch the high voltage lead of the megohmmeter to the flexible electrode.	Hold the high voltage lead using the insulating handles and make electrical contact with the flexible electrode.
4	Measure resistance.	Use the megohmmeter to measure resistance.
5	Calculate resistivity	Resistivity $\rho = R \times \left(\dfrac{A}{d}\right)$

D.   Monitor Static on Incoming and Outgoing Material

One common root cause of static problems is having high charge on the stockroll of material delivered to the coater. Referring to the coater thread-up shown in Figure 4, monitoring E_{unwind} and V_3 identifies high charge on the incoming material. Having baseline measurements of E_{unwind} enables unusually high readings to be recognized. Logging V_3 as part of the quality assurance program for a coater will automatically identify high static on incoming material using a permanently mounted sensor.

Similarly, the static on the out-going material will help eliminate static problems from subsequent operations or at your customer's site. Logging V_{14} and E_{18-19} as part of the quality assurance program for a coater and providing this data to downstream operations with build confidence and help eliminate static problems.

IV.   CONCLUSIONS

Requirements for static control during coating operation are becoming more demanding as film based products become more complex. Staying ahead of static problems is accomplished by implementing the following measures as part of the quality assurance program for a coater.

1. BASELINE: Collect and document baseline electrostatic fieldmeter and non-contacting electrostatic voltmeter measurements. Use these measurements to identify sources of static when problem occur.

2. VERIFY STATIC DISSIPATORS: Verify that static dissipaters (ionizers, tinsel, etc.) are functioning properly.

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