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Electrostatic Charge Control in Slitting Operations

Kelly Robinson, PhD, President
Electrostatic Answers, LLC., Rochester, NY
Kelly.Robinson@ElectrostaticAnswers.com

ABSTRACT

Controlling the electrostatic charge on films during a slitting process is especially challenging because the line speed is typically fast (150 to 1500 m/min) and the slitter winder is congested with hardware to handle multiple slit rolls. Static in slitting should be controlled at 3 different locations within the process; (1) at the unwinding master roll, (2) after contact with every polymer covered rollers such as cleaning rollers or drive rollers, and (3) at the winding slits.

For robust performance, static must be controlled throughout the process. Static charging fundamentals are presented to explain that seeking to controlling static only at the end of a process is ineffective and will almost certainly cause static problems in subsequent operations.

Presented is a typical slitter where static abatement is needed. Practical methods to measure static are illustrated using an electrostatic fieldmeter and non-contacting electrostatic voltmeters. Measurement locations are identified by starting at the unwinding master roll and moving through the tread-up to the winding slits. These static measurements are analyzed to determine the source of the charging and to identify locations for static dissipation technology such as tinsel, Static String®, or ionizers to effectively neutralize the electrostatic charge on the surface of the film.

For robust static performance, charge dissipation technology should:

1. Limit the electric field measured on free spans to less than 2 KV/cm, and
2. Limit the electric field measured on winding slits to less than 5 KV/cm.

I. INTRODUCTION

Requirements for static control during slitting manufacturing 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.

Slitting operations are particularly demanding. Slitting line speeds are typically very fast (150 to 1500 m/min). The film path near the winders is congested with hardware to handle multiple slit rolls. And, process problems during slitting are especially costly because the slit product has high value.

Systematic diagnosis of static issues is valuable [1]. Basic electrostatic measurements using an electrostatic fieldmeter and non-contacting electrostatic voltmeters are reviewed. The charge density on the film is estimated using the measured values. Next, these basic measurements are used to identify the sources of charging in a case study of a typical precision slitting operation. Static measurements locations are identified and analyzed to diagnose static problems. Finally, installation of active and passive ionization technology appropriate for each source of static charging is described. The variety of active and passive ionizers is given elsewhere [1] including a discussion of their relative performance.

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 slitting operation. When diagnosing a static problem or working to identify the source of static charging in a slitting operation, two 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. And, non-contacting electrostatic voltmeter is used to measure the electric potential of the film when it is wrapped on an idler roller. With measurement data, the charge density on the film surface can be estimated and tracked through the slitting operation.

A. Electrostatic Fieldmeter

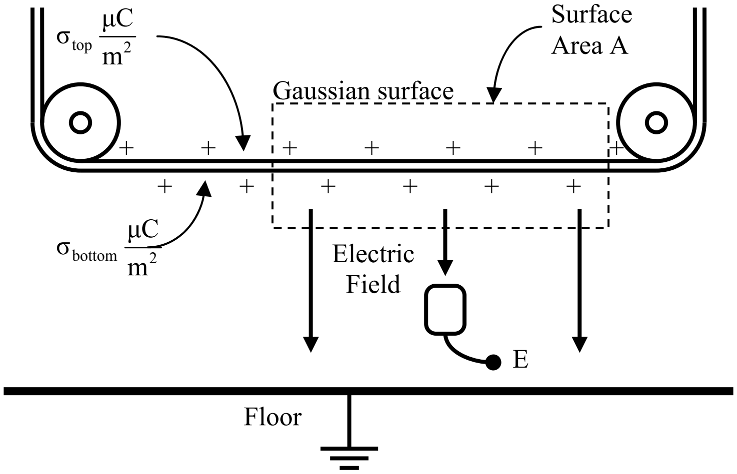

Figure 1: The film on this span between two idler rollers has charge density σ_{top} on the upper surface and σ_{bottom} on the lower surface. The electric field between the film and the floor is uniform because the film is parallel to the floor. The charge density is estimated by measuring the electric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

$$\begin{gathered}\sigma_{top} + \sigma_{bottom} = \varepsilon_0 E \\ \left(\sigma_{top} + \sigma_{bottom}\right)\left[\frac{\mu C}{m^2}\right] \approx 1.0 E\left[\frac{KV}{cm}\right] \quad \text{: Film span parallel to floor}\end{gathered} \tag{2}$$

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).

$$\begin{gathered}\sigma_{top} + \sigma_{bottom} \approx \frac{\varepsilon_0 E}{3} \\ \left(\sigma_{top} + \sigma_{bottom}\right)\left[\frac{\mu C}{m^2}\right] \approx \frac{E}{3}\left[\frac{KV}{cm}\right] \quad \text{: Isolated film span away from floor}\end{gathered} \tag{3}$$

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. Non-contacting Electrostatic Voltmeter

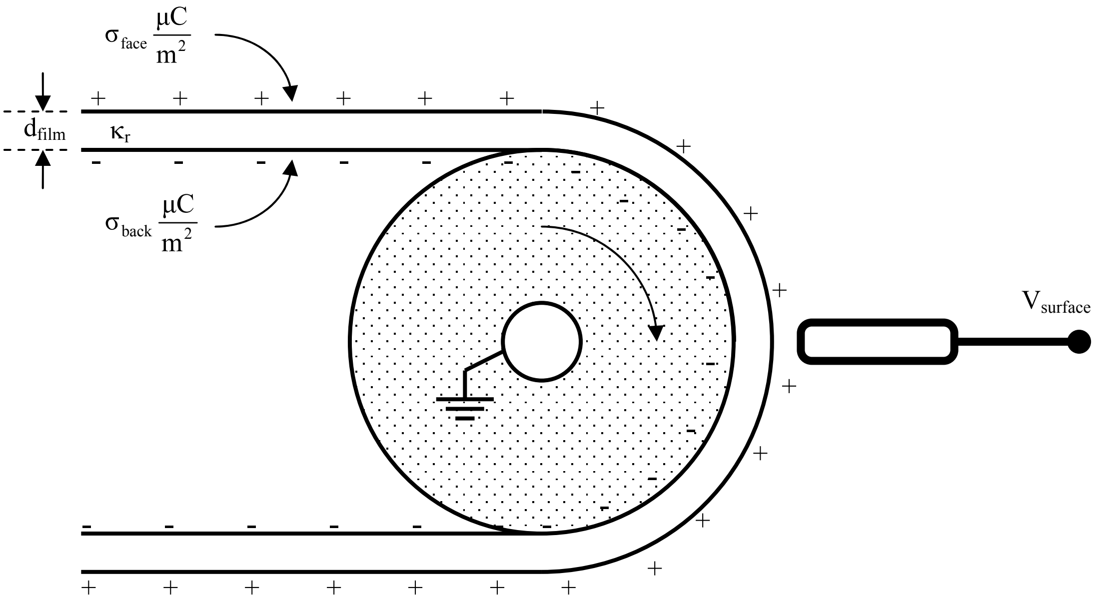

Figure 2:. Charged film is wrapped around a smooth, metal idler roller. The non-contacting electrostatic voltmeter measures only the charge density σ_{face} on the exposed face side of the film

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.

$$\begin{gathered} \sigma_{exposed} = \left(\frac{\varepsilon_0 \kappa_r}{d_{film}} \right) V_{surface} \\ \sigma_{exposed} \left[\frac{\mu C}{m^2} \right] \approx 20 \frac{V_{surface} [V]}{d_{film} [\mu m]} \end{gathered} \tag{5}$$

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 $\mu C/m^2$.

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.

III. CASE STUDY OF PRECISION SLITTING OPERATION

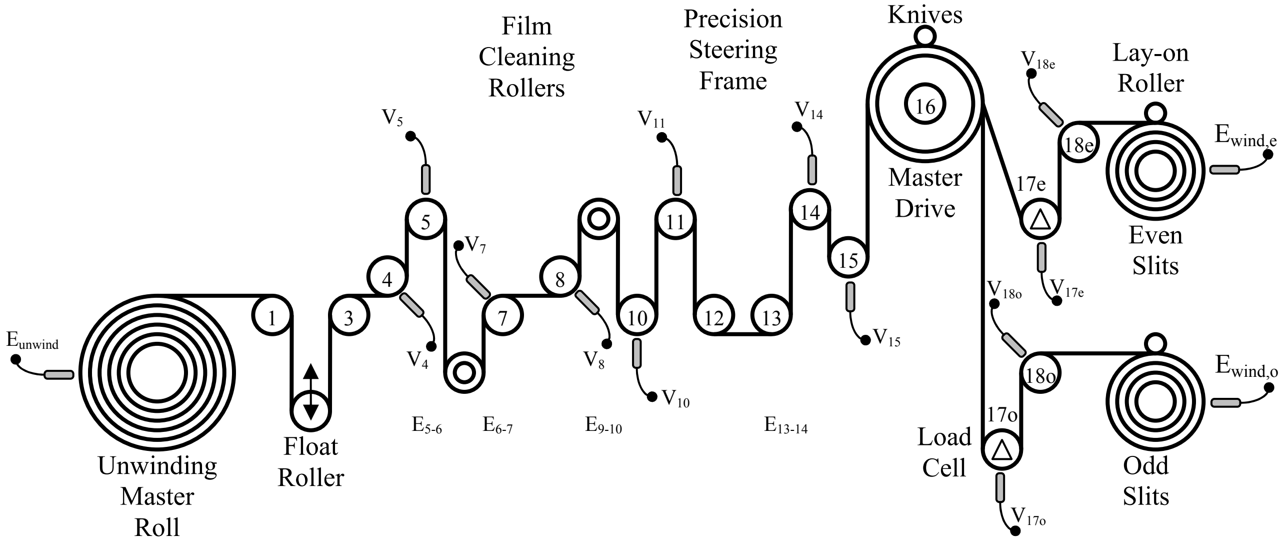

Figure 3: Each roller is numbered in this thread-up diagram for a typical slitter. Measurement locations needed to identify sources of static charging are identified.

Figure 3 is the film thread-up diagram for a conceptual slitter used for a precision slitting operation. This slitter features a float roll to control the unwinding tension, a pair of film cleaning rollers, a precision steering frame just prior to slitting, load cells to control winding tension, and separate winders for odd and even slits. The measurements needed to characterize the static performance of the operation are identified. The overall performance is measured by comparing the electric field measured at the unwinding master roll with the electric field measured on the winding slits. Key elements to be evaluated as potential sources for film charging are the unwinding master roll, film cleaning rollers, the precision steering frame, and slitting on the master drive roller.

A. Unwinding Master Stockroll

The two common sources of static charging at the unwinding master roll are (1) tribocharging between the front and back sides of the film at the unwinding nip and (2) static charge on the film from previous operations. Three measurements help identify the source of static charge in the unwinding stockroll; E_{unwind}, V_4 and V_5. Tribocharging between the front and back sides of the film typically result in monotonic increase of E_{unwind} from zero to a relatively steady level after only a few laps have been unwound. Charge from previous operations results in E_{unwind} being highly variable. Voltmeter readings V4 and V5 measure the charge on the front and back film surfaces. Typically, a few idler rollers and a float roller do not add substantial charge to the film, so measurements taken at rollers 4 and 5 are fair representations of the charge on the unwinding master roll.

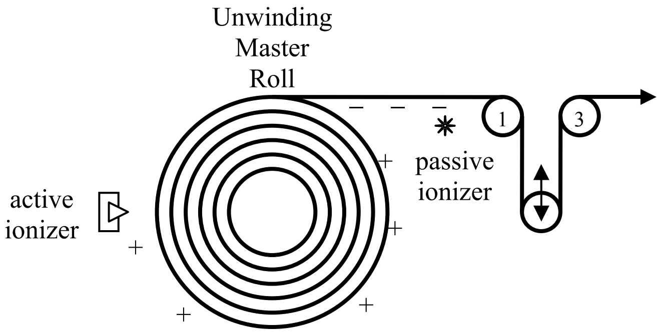

Figure 4: Two static dissipation devices are needed to neutralize charge on the film unwinding from the master roll.

Figure 4 shows the appropriate charge dissipation technology for substantial charge on the film unwinding from the master roll. Static charge separates in the nip as the film unwinds. The active ionizer (pin ionizer powered by a high voltage power supply) controls the charge on the unwinding master roll. The passive ionizer (brush, tinsel, Static String ®) dissipates the charge on the film surface as it unwinds from the master roll.

B. Cleaning Rollers

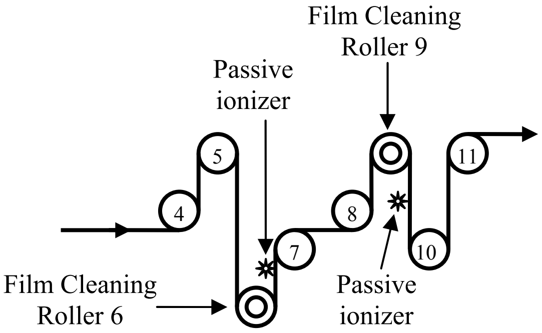

Figure 5: Two static dissipation devices are needed to neutralize the film after contact with cleaning rollers.

Cleaning rollers are commonly soft polyurethane or tacky rollers that very effectively remove dust and debris from the film surface. The rollers often deposit high levels of static charge on the film because the surface of these rollers is designed to make intimate contact with the film surface. Referring to the Figure 3, the difference between the quick, hand-held measurements $E_{6\text{-}7}$ and $E_{5\text{-}6}$ characterize the charge deposited on the film by cleaning roller 6. The film charge from cleaning roller 6 may be measured more precisely by voltmeter measurements V_7 and V_5. Similarly, the quick, hand-held measurements $E_{9\text{-}10}$ and $E_{6\text{-}7}$ characterize the charge deposited on the film by cleaning roller 9. The film charge deposited by cleaning roller 9 may be measured more precisely by voltmeter measurements V_{10} and V_8.

Figure 5 shows the appropriate technology to dissipate charge from the cleaning rollers. The passive ionizer on span 6-7 dissipates the film surface as it exits cleaning roller 6. The passive ionizer on span 9-10 dissipates the film surface as it exits cleaning roller 9.

C. Precision Steering Frame

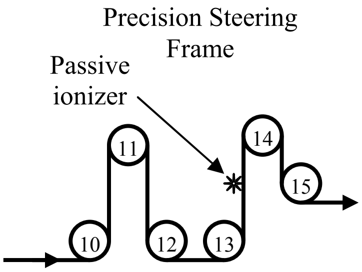

Figure 6: Only a single passive ionizer is needed to dissipate film charging from a steering frame.

In the steering frame shown in Figure 6, rollers 11 and 14 are fixed and rollers 12 and 13 are on a frame that can twist to steer the film. As the steering frame moves, the web must slip over rollers 12 and 13. This slip can be a significant source of static charging. The difference between the quick, hand-held fieldmeter measurements E_{13-14} and E_{9-10} characterize the charging from the steering frame. The film charge deposited by the steering frame may be measured more precisely using voltmeter measurements V_{14} and V_{11}.

Only a single, passive ionizer is needed to dissipate the charge deposited on the film by a steering frame because only one surface of the film contacts the rollers on the twisting steering frame.

D. Slitting

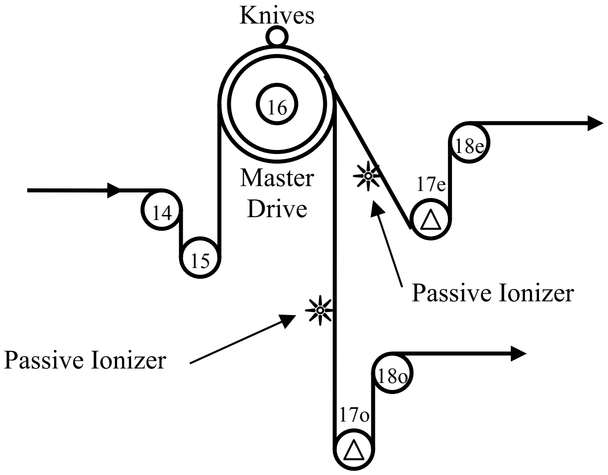

Figure 7: Two passive ionizer are needed to dissipate film charging after slitting.

During slitting, the knives make high pressure contact with the film that can result in bands of high charge along slit edges and in regions where the film makes high pressure contact with the backing roller. The passive ionizers are positioned to neutralize charge from contact with the backing roller, which is also the master drive roller for this slitter. If the bands of charge along slit edges prove to be problematic, an active ionizer would be needed to neutralize the charge.

E. Winding Slits with Lay-on rollers

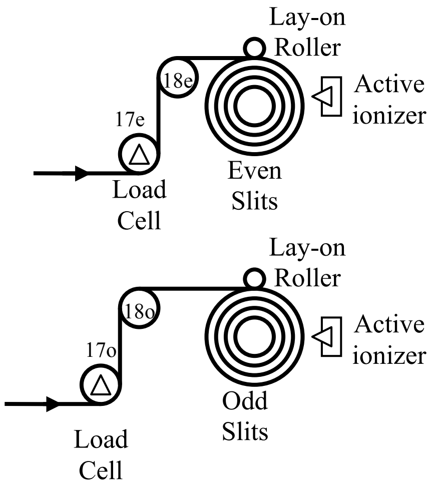

Figure 8: Active ionizers are required to control charging from winding lay-on rollers.

The goal is to wind an electrically neutral film. Fieldmeter and voltmeter readings just prior to winding should confirm that the film is neutral. If charge is present, strong effort is needed to locate and eliminate charge at the source. Lay-on rollers used to build the winding slits can be a significant source of charging. Active ionizers are needed to neutralizing static charge because this area of the slitter is typically congested and the winding roll diameter varies. Passive ionizers are very sensitivity to the spacing to the film making them ineffective for unwinding and winding.

IV. CONCLUSIONS

Requirements for static control during slitting manufacturing are becoming more demanding as film based products become more complex. Static charge can be neutralized most effectively at the source of charging. Using a systematic diagnosis of static issues is particularly valuable for slitting operations because the slitting occurs near the end of the production process where the film has high value. An electrostatic fieldmeter is the workhorse for diagnosing static problems because readings are relatively quick and easy to make. The static charge density on the film surfaces can be measure more precisely using non-contacting electrostatic voltmeters. A combination of active and passive ionizers is needed to dissipate charge in a typical slitting operation. Active ionizers such as pin ionizers powered by high voltage power supplies are required for neutralizing charge on the unwinding master roll and on the winding slits because the roll diameter varies. Active ionizers are effective over a relative wide variation in spacing between the ionizer and the film surface. Passive ionizers such as brushes, tinsel or Static String ® are effective in neutralizing the film charged by cleaning rollers or steering frames.

V. REFERENCES

[1] K. Robinson and W. D. Durkin, “Electrostatic Issues in Roll-to-Roll Manufacturing Operations,” in conference record, *2007 IEEE Industry Applications Conference*, Paper 22P1, 9/23-27/2007.