CONTROLLING STATIC ON AN UNWINDING ROLL

By

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ABSTRACT

Excessive static charges on insulating webs are the root cause for a number of problems in roll-to-roll manufacturing operations. Static charges attract contaminants and cause discharges that can ignite flammable vapors, shock operators, damage machine control systems, and change the surface chemistry of carefully formulated products. Webs are commonly unwound and wound several times in a manufacturing operation. For example, webs formed by an extrusion process are wound. The roll may be unwound in a coating, slitting, or converting process and wound a second time in a customer roll. Finally, the roll may be unwound a third time in a customer application such as printing or in a label application process.

Static charges on the web are stored in each wound roll. Each time a roll is unwound is a unique opportunity to neutralize static. Proposed here is a new method for neutralizing static on unwinding rolls. The static control method has three key elements. First, a high performance static bar must be located to neutralize the outside surface of the unwinding roll. Second, a static bar must be located downstream of the first conveyance roller to neutralize the inside surface of the web. Third, the first conveyance roller after the unwinding roll must contact the inside surface of the web.

The method to neutralize static on an unwinding roll is analyzed to show that static charge separated at the unwinding nip by tribocharging may be substantially reduced. The same method also reduces static charges wound into the roll from previous operations.

Finally, the effect of the first conveyance roller on static control is discussed. The web exiting the unwinding roll is likely to have a high level of static that will cause a static discharge known as pre-nip ionization that occurs in the gap between the charged web and the surface of the first roller prior to contact. Pre-nip ionization requires that the first conveyance roller contact the inside surface of the web. Otherwise, the charge neutralization performance of this method is compromised and the web will remain highly charged through the production operation resulting in high static in the winding roll.

NOMENCLATURE

Parameter	Units	Description
A_{ROLL}	m^2	surface area of an unwinding roll (excludes side walls)
C_{ROLL}	F	capacitance of the unwinding roll
D_{CORE}	m	roll core diameter, inner diameter of unwinding roll
D_{ROLL}	m	outer diameter of unwinding roll
d_{WEB}	m	web thickness
E_{SPAN}	V/m	electric field measured on a web span
Q_{ROLL}	C	charge on the outside surface of an unwinding roll
V_{ROLL}	V	voltage (electric potential) of the unwinding roll
V_{WEB}	V	web surface potential
W_{WEB}	m	web width
ε_0	F/m	permittivity of free space; 8.854×10^{-12} F/m, physical constant
κ_{WEB}	1	dimensionless relative dielectric constant, material property
σ_{WEB}	C/m^2	web surface charge density
$\sigma_{WEB,IN}$	C/m^2	surface charge density on inside web surface
$\sigma_{WEB,OUT}$	C/m^2	surface charge density on outside web surface

INTRODUCTION

Improvements in printing, embossing and etching technologies enable roll-to-roll (RtR) manufacturing to be used to produce a wide variety of new products including flexible electronic circuits, electronic displays, solar cells, and biologically active sensors. Static charges that accumulate on the surfaces of an insulating polymer webs during production can cause a number of problems including dust attraction, sticking or jamming of cut sheets, and static discharges. Discharges damage the surfaces of carefully designed layers, reset machine control systems, ignite flammable solvent vapors and even injure operators.

Controlling static in RtR operations has been a challenge at least since the 1950's when electrostatic charge attracted dust to motion picture film [1]. New and emerging products built using RtR operations will require better static control because electronic devices, thin layers of engineered materials, and biologically active layers are sensitive to contamination and changes in surface chemistry driven by static discharges.

Many devices for neutralizing static charge are available. These devices all ionize air using a low energy corona discharge at the sharp tips of electrodes. Static neutralizers can be broadly categorized at either passive or active. Passive devices include static brushes, tinsel, and ionizing strings that simply needed to be connected to ground potential to operate. For their operation, passive devices rely on the electric field from the static charge on the web. Passive neutralizers must be the nearest grounded object to the web, which usually requires that they be located very near the web surface, typically in the range 0 – 3 cm. When the electric field is low, passive device generate no ions. As a result, passive devices are ineffective in neutralizing static charge below a threshold surface charge density of about 1 $\mu C/m^2$.

Active devices are energized by a high voltage power supply. These devices include nozzle ionizers, static blowers and static bars. The electrodes in active ionizers are typically energized by a sinusoidal waveform that generates corona ions of both polarities. Consequently, there is no turn-on threshold for operation and active ionizers can completely neutralize static charge. Ions generated by active ionizers are mobile and they can move a significant distance through the air from the energized electrodes to the web surface to be neutralized, typically in the range 1 – 10 cm.

Some modern static bars are designed to effectively neutralize charged objects at a long distance from the ionizer. The electrodes in these ionizers are energized by voltage pulses rather than by a sinusoidal voltage. These long range ionizers can effectively neutralize an unwinding roll at a distance in the range 0.5 – 2 meters.

Proposed here is a new method for neutralizing static charges on unwinding rolls that is enabled by long range static bars. This method is effective in neutralizing static charges on unwinding rolls from two common root causes; tribocharging between the inner and outer surfaces of the unwinding web and static charge wound into the roll from prior operations.

STATIC CHARGE ON UNWINDING ROLLS

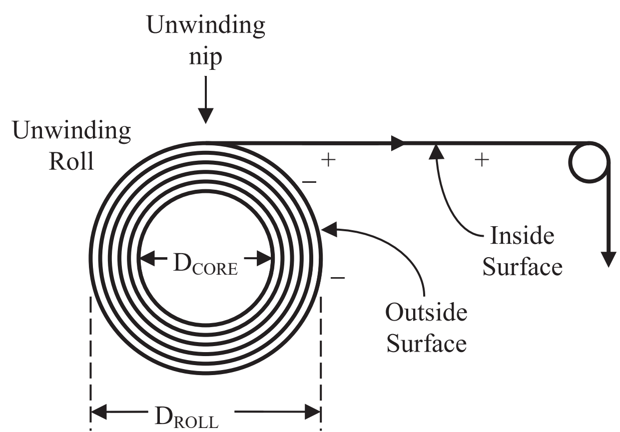

Figure 1 – The web separates from the roll at the unwinding nip. The inside surface has positive charge and the outside surface has an equal amount of negative charge.

<u>Tribocharging between Inside and Outside Web Surfaces</u>

When two chemically different surfaces touch and separate, charge separation occurs by triboelectrification. One surface will have positive charge and the other will have an equal amount of negative charge. Triboelectrification is a common source of static when unwinding laminates or coated webs because the inside surface is chemically different from the outside surface. The inside surface in Figure 1, peels away from the outside surface of the roll at the unwinding nip. In this case, the inside surface has a positive charge and the outside surface has negative charge after separation.

While tribocharging is well documented, it is not well understood. The triboelectric series in Table 1 provides guidance on the polarity of charge on material surfaces that touch and separate. For example, human skin is a biological material at the top of the triboelectric series and PET is a synthetic polymer near the bottom. After a human touches a PET web, the skin will have a positive static charge because it is higher on the triboelectric series. A “finger print” of negative charge will be on the PET web surface because it has a lower position. Generally, greater separation on the triboelectric series indicates greater charging between surfaces. For example, a coating with a polyurethane binder is triboelectrically well suited for a cellophane web to minimize tribocharging because these two materials are adjacent on the triboelectric series.

Table 1: Triboelectric Series [2]

Less human processing ↑

Positive	inorganics & biological materials	human skin
		asbestos
		glass
		human hair
		mica
	exception	nylon
	inorganics & biological materials	wool
		cat fur
		silk
		alumina
	natural fibers	paper
		cotton
		wood
Nearly Neutral	exceptions	steel
		poly(methyl methacrylate) (Elvacite®)
	natural resins	wax
		amber
		latex
	metals	copper
		brass
		gold
		platinum
Negative	exceptions	synthetic rubber (neoprene)
		sulfur
	biopolymers	acetate (Rayon®)
		acrylic (Orlon®)
		cellophane
	synthetic polymers	polyurethane
		polycarbonate
		polyvinylidene chloride (Saran®)
		polystyrene
		polyethylene
		polypropylene
		polyimide
		polyethylene terephthalate (PET)
	chloropolymers	polyvinyl chloride (PVC)
	fluoropolymers	polychloro trifluoro ethylene (PCTFE)
		polyvinylidene fluoride (Kynar®)
		polytetrafluoroethylene (PTFE) (Teflon®)
	exception	silicone rubber

↓ More human processing

Many materials are missing from this version of the triboelectric series and most materials remain to be tested to determine their location. In this version, I have categorized materials to provide guidance on the position of unlisted materials. For example, polyvinyl chloride is the only entry for chloropolymers. Other chlorine containing hydrocarbons should have charging properties similar to PVC. Note that there are several exceptions. For example, nylon is a synthetic polymer that charges much more positively than would be expected. So, the charging properties of an unlisted material should be tested to confirm its location in the triboelectric series.

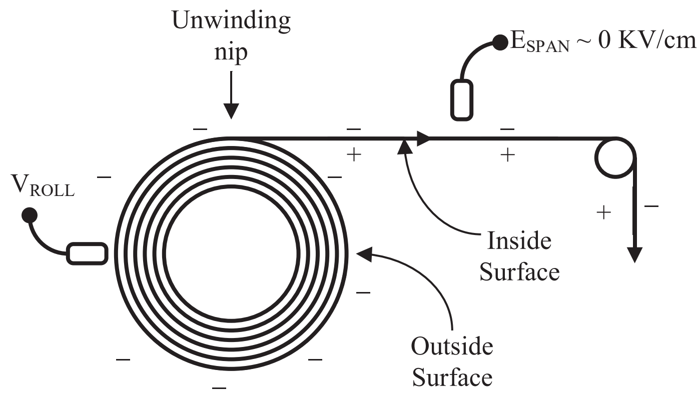

Figure 2 – When tribocharging is the source of static, the electric field measured on the first web span is approximately zero. However, the voltage on the unwinding roll is very high and can exceed 50 KV. The voltage can cause sparks from the roll surface to the core or to other nearby grounded objects.

As the roll in Figure 2 continues to unwind, the exiting web is electrically neutral having a positive charge density on the inside surface and a equal negative charge density on the outside surface. When tribocharging is the source of static, the electric field E_{SPAN} measured on the first span is approximately zero, while the voltage on the unwinding roll is very high.

The voltage on the unwinding roll may be found by {1} if the capacitance C_{ROLL} is known.

$$Q_{ROLL} = C_{ROLL} V_{ROLL} \qquad \{1\}$$

The charge Q_{ROLL} on the surface of the roll can be written in terms of the web charge density σ_{WEB} in {2}.

$$Q_{ROLL} = \sigma_{WEB} A_{ROLL} = \sigma_{WEB} (\pi D_{ROLL} W_{WEB}) \qquad \{2\}$$

The roll capacitance C_{ROLL} is estimated in {3} as the capacitance between concentric cylinders [3].

$$C_{ROLL} = \frac{2\,\pi\,\kappa_{WEB}\,\varepsilon_0\,W_{WEB}}{\ln\left(\frac{D_{ROLL}}{D_{CORE}}\right)} \qquad \{3\}$$

Solve {1} for V_{ROLL} and use {2} and {3} to find {4} that is plotted in Figure 3 for a 0.1 m (~4 inch) roll core diameter.

$$V_{ROLL} = \frac{\sigma_{WEB} D_{ROLL}}{2\;\kappa_{WEB}\;\varepsilon_0} \ln\left(\frac{D_{ROLL}}{D_{CORE}}\right) \qquad \{4\}$$

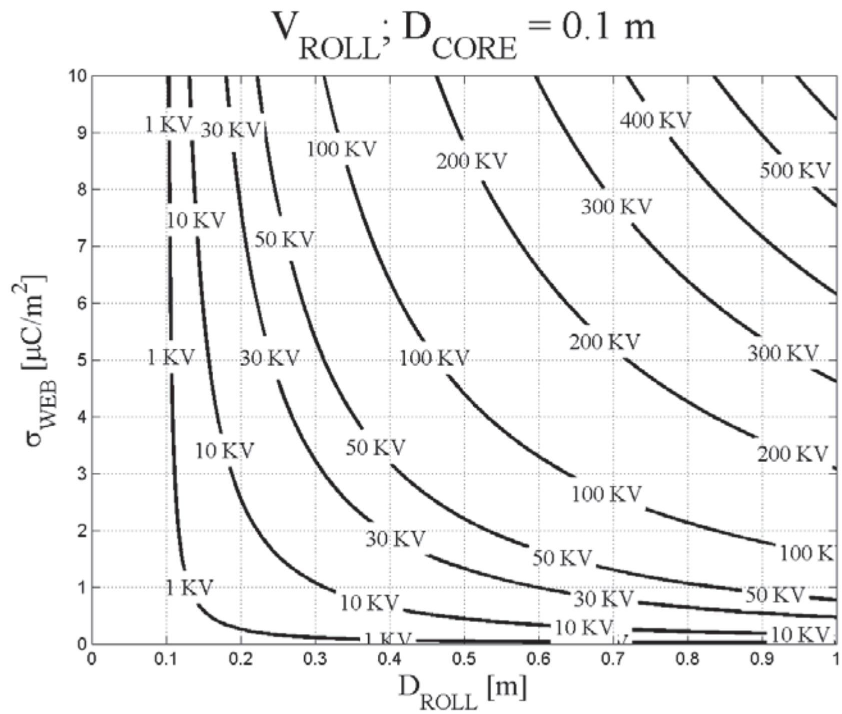

Figure 3 – For a web charge density σ_{WEB} of 1 $\mu C/m^2$ that is typical of tribocharging, the voltage of a large unwinding roll (D_{ROLL} ~ 1 m) can exceed 50 KV.

For a surface charge density of 1 $\mu C/m^2$, which is typical of tribocharging, the voltage of large rolls (1 m diameter) can exceed 50 KV. This voltage is sufficiently high to cause sparks from the roll surface to the core along the sidewall of the roll. Sparks may also occur between the roll surface and nearby grounded objects such as the machine frame or operators.

Static Charge from Previous Operations

A very common root cause for static problems is shown in Figure 4 where a web with positive charge on one surface and an equal amount of negative charge on the other surface is wound onto a roll. As the roll continues to wind, the positive charge on the outside lap of the roll is balanced by the negative charge on the web that forms the next lap.

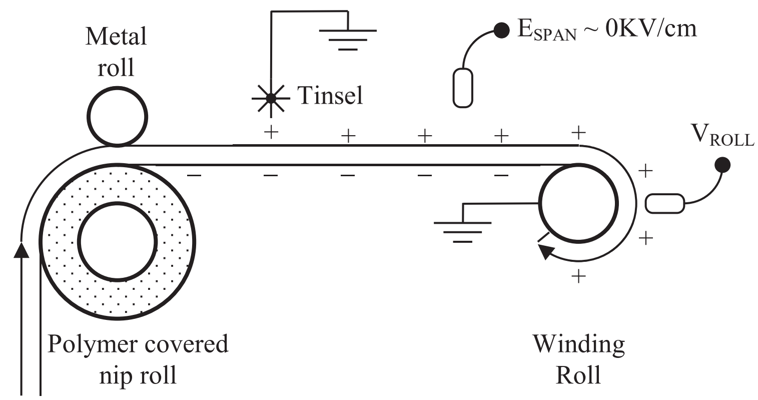

Figure 4 – The web is charged by contact with the polymer covered nip roller. While tinsel is intended to neutralize static, it is located on the wrong side of the web resulting in positive charge on the outside surface and an equal amount of negative charge on the inside surface of the web.

The winding roll in Figure 5 has positive charge only on the outer lap that is electrically analogous to the unwinding roll in Figure 2. The analysis {1} through {4} and Figure 3 apply to this winding roll.

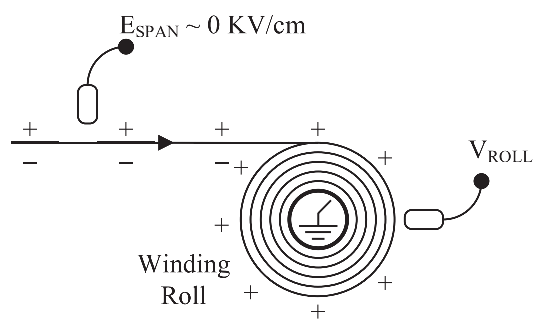

Figure 5 – The web with positive charge on the outside surface and an equal amount of negative charge on the inside surface is wound resulting in positive charge on the outside surface of the roll.

The web surface charge density in Figure 6 may be measured using a non-contacting electrostatic voltmeter. The web thickness d_{WEB} is much smaller than the radius of the grounded metal roller, so the measurement geometry is approximately planar. The surface potential V_{WEB} is related to the surface charge density $\sigma_{WEB,OUT}$ by the capacitance of a parallel plate geometry as in {5}.

$$\sigma_{WEB,OUT} = \frac{\kappa_{WEB}\ \varepsilon_0}{d_{WEB}} V_{WEB} \qquad \{5\}$$

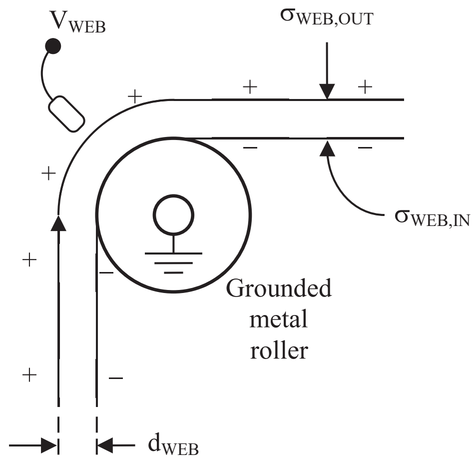

Figure 6 – A non-contacting electrostatic voltmeter measures the surface potential V_{WEB} of the web wrapped on a grounded metal conveyance roller. V_{WEB} varies only with the surface charge density $\sigma_{WEB,OUT}$ on the exposed surface of the web.

For a 50 μm thick (2 mil) PET web (relative dielectric constant $\kappa_{WEB} = 3.0$), a typical surface potential of 10 volts represents a surface charge density $\sigma_{WEB,OUT}$ of 5 $\mu C/m^2$. Even though the electric field E_{SPAN} on the span leading to the winding roll is zero, Figure 3 shows that the surface potential of this winding roll can easily exceed 100KV.

When this roll is unwound in the next operation, the charge distribution is identical to that in Figure 2. The static observed when unwinding a web with this very common pattern of charge, where one side has positive charge and the other side has an equal amount of negative charge, is indistinguishable from tribocharging. This is significant for two reasons. First, a method that effectively neutralizes unwind tribocharging will also neutralize this pattern of static charge on the web from previous operations. Second, during the development and commercialization of new products, coatings and laminates are formulated to minimize unwind tribocharging. However, this tribocharging must be evaluated using rolls wound with an electrically neutral web because static charge from conveyance will be indistinguishable from unwind tribocharging. These two root causes of static are quite different and require uniquely different solutions. The solution for conveyance charging is the proper selection and location of static neutralizers along the conveyance path. In contrast, unwind tribocharging must be solved by adjusting the product formulation.

NEUTRALIZING STATIC CHARGE ON UNWINDING ROLLS

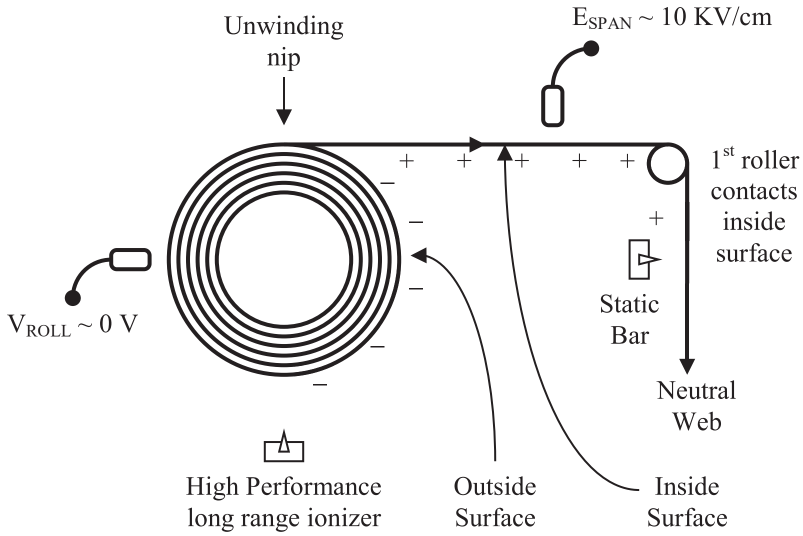

Figure 7 – A high performance, long range ionizer neutralizes the charge on the outside surface of the unwinding roll. A static bar after the first conveyance roller neutralizes the charge on the inside web surface. The web exiting the unwind area is electrically neutral.

Static on the unwinding roll in Figure 7 is effectively neutralized using 2 ionizers; a high performance, long range ionizer and a traditional static bar. A high performance, long range ionizer must be used to neutralize the outside surface of the unwinding roll because the distance from the ionizer to the roll increases as the unwinding roll expires. Also, the unwind geometry is often complex and congested. The unwinder may be a turret with several spindles. And, a crane is often used to lift rolls. The unwind geometry may require that the high performance ionizer be located some distance from the unwinding roll.

The role of the high performance, long range ionizer is to neutralize the charge on the outside surface of the unwinding roll, which is negative in Figure 7. The effectiveness of the high performance ionizer may be verified using two measurements.

1. The voltage V_{ROLL} of the unwinding roll should be nearly zero.
2. The electric field E_{SPAN} on the span from the unwinding roll to the first roller should be very high; 10 KV/cm or higher.

A static bar is used to neutralize static charge on the inside surface of the web. This ionizer could be located along the web span from the unwinding roll to the first roller. However, the location of this span varies as the roll expires, and the performance of static bars varies with the distance to the web. And, the geometry of this span is often complex and congested. For example, a rotating turret may move the location of this first span by a meter or more. Locating the static bar after the first roller greatly simplifies the geometry. In addition, this location is often much more accessible for ionizer maintenance and cleaning.

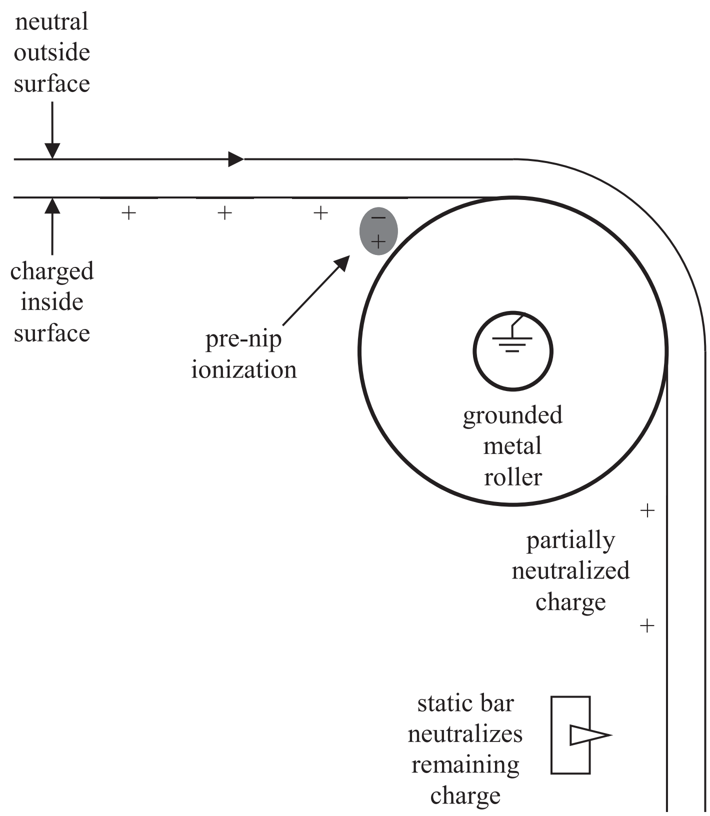

Figure 8 – Pre-nip ionization occurs in the air gap between the charged web and the roller surface prior to contact. The web surface that contacts the roller is partially neutralized.

The location of the first roller is critical because the web will likely have high static. The high static on the web in Figure 8 generates an electrical discharge in the gap between the web and the roller surface just before the web touches the roller; pre-nip ionization. Ions of both polarities are generated. Negative ions are attracted to the web, which partially neutralizes the charged, inside surface. Positive ions move towards the grounded roller. The result is that the web exiting contact with the first roller is partially neutralized. The static bar located just downstream of the first roller neutralizes the charge remaining on the web inside surface.

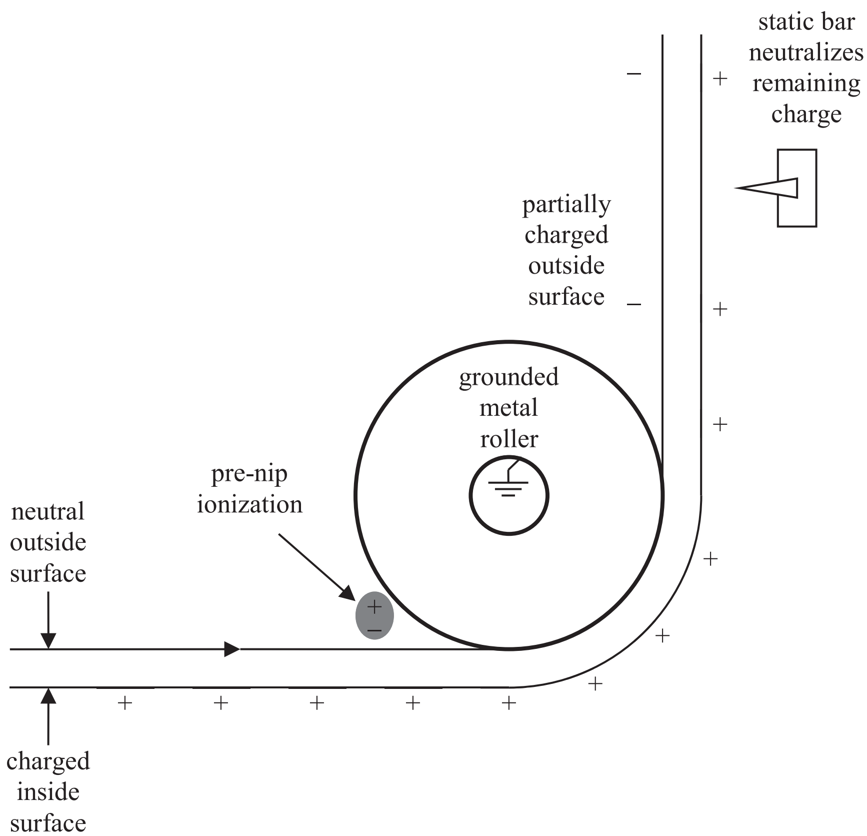

Figure 9 – Pre-nip ionization occurs in the air gap between the charged web and the roller surface prior to contact. The web surface that contacts the roller is partially charged.

The location of the first roller in Figure 9 improperly contacts the neural outside web surface. The high static on the web generates pre-nip ionization. Ions of both polarities are generated. Negative ions are attracted towards the web, which partially charges the previously neutral surface. Positive ions move towards the grounded roller. The web exiting contact with the first roller now has charge on both sides. The static bar located just downstream of the first roller neutralizes the charge remaining on the web. The result is that the web has positive charge on the inside surface and an equal amount of negative charge on the outside surface. The performance of the static neutralization system has been compromised.

FUTURE WORK

While the proposed method for neutralizing unwinding rolls has been implemented in several production operations with good results, a quantitative evaluation remains to be done.

1. The efficiency of the long range ionizer should be measured as a function of speed and distance from the unwinding roll.
2. The performance of the static bar located after the first conveyance roller should be measured to determine whether it can be replaced by tinsel or ionizing string.
3. The effect of pre-nip ionization at the first conveyance roller should be measured to determine whether a polymer covered roller can be used in cases where the unwinder geometry requires the first conveyance roller to contact the outside web surface.

SUMMARY

1. Each time a roll is unwound is a unique opportunity to neutralize static.
2. Two common root causes of static on the unwinding roll are:
    - 2.1. tribocharging between the inside surface and the outside surface at the unwinding nip, and
    - 2.2. charge that has accumulated on the web from previous operations where one side has positive charge and the other side has an equal amount of negative charge.
3. While static charges on the unwinding roll from these two root causes are identical and indistinguishable, their countermeasures are quite different.
    - 3.1. Tribocharging is minimized by adjusting the product formulation.
    - 3.2. Static that accumulates from previous operations is neutralized by the static control system installed along the conveyance path.
4. The static neutralization method for the unwinding roll has three key elements:
    - 4.1. a high performance, long range static bar,
    - 4.2. a traditional static bar, and
    - 4.3. a first conveyance roller contacting the inside web surface.
5. The high performance static bar neutralizes static on the surface of the unwinding roll.
6. The traditional static bar neutralizes static on the inside surface of the web. This bar should be located downstream of the first conveyance roller.
7. The first conveyance roller must contact the inside surface of the web so that pre-nip ionization partially neutralizes the charged inside web surface.
8. Charge neutralization performance is compromised if the first conveyance roller contacts the outside web surface,.

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2. Robinson, K. S., “Triboelectric Series by Electrostatic Answers,” www.ElectrostaticAnswers.com, 9/01/2009.
3. Smythe, W. R., “2.04. Cylindrical Capacitors,” Static and Dynamic Electricity, 3rd ed., McGraw-Hill, New York, 1968, pg. 28.

Controlling Static on an Unwinding Roll **K. Robinson,** Electrostatic Answers LLC., USA

Name & Affiliation	Question
Clarence Klassen, KlassEngineering	We know about the dangers of the static in the roll and in the web. What are the hazards to personnel with these high performance ionizers and static bars? What can be done to protect personnel from that?
Name & Affiliation	**Answer**
K. Robinson, Electrostatic Answers LLC	Thanks to modern technology, there is a class of ionizers called shockless ionizers where the pinpoints are either resistively or capacitively coupled power supplies. You can touch them with your finger and not experience a shock. If an operator forgets and leaves them on there is no concern to shocking the operators. Many shockless bars are also rated for use in hazardous locations where solvents are present.
Name & Affiliation	**Question**
Clarence Klassen, KlassEngineering	Is there any damage associated with the static discharging through roller bearings?
Name & Affiliation	**Answer**
K. Robinson, Electrostatic Answers LLC	Usually the answer is no. Damage to the bearings due to static is not a worry. If you are running a corona discharge treater where there is a lot of current it could be a problem. If you are driving that current through ball bearings then you have to worry about damage to the bearings. For the case of static there are only micro amps of current. You do not have to worry about damage to the bearings due to static.
Name & Affiliation	**Question**
Bob Lucas, Winder Science	I was under the impression that when a web goes over a roll and departs from that roll, there is a film splitting mechanism that is a static terminator. Does that imply that we need to have static eliminating devices throughout the web process for those webs that are sensitive?
Name & Affiliation	**Answer**
K. Robinson, Electrostatic Answers LLC	It is a matter of degree. In the winter, every time I take a step on the carpet I am putting a little bit of charge onto my shoes. Usually I have to take hundreds of steps before I get a shock from the doorknob. The same is true in a machine. The charge that is separated by a single contact with a roller is usually not enough to cause a problem. You need to contact many rollers before you need to install a neutralizer. The one exception to that rule of thumb is a nip where there is a high pressure contact. A single nip can generate sufficient charge to cause sparks. If you are concerned about that, there needs to be a neutralizer, static string or tinsel after every nip roller.

Name & Affiliation	**Comment**
Bob Lucas, Winder Science	In dry winter conditions in a super calendar where we have intense nip, it is evident that the entire machine is one ball of energy and seeing sparks 2-3 feet is not uncommon.
Name & Affiliation	**Answer**
K. Robinson, Electrostatic Answers LLC	OK
Name & Affiliation	**Question**
Günther Oedl, Brueckner Machinery	We learned from your presentation that with free span measurement, we can't discern static if one side of the web is positive charged and the other side is negative. Is there a simple way to capture/measure this type of static?
Name & Affiliation	**Answer**
K. Robinson, Electrostatic Answers LLC	Yes. In my paper, figure 6 shows a volt meter measuring the surface of a film that is wrapped over a grounded metal conveyance roller. A volt meter measurement will detect the charge on just one surface of the film without looking at both. When you are working on static issues, it is good to use both electrostatic field measurements and volt meter measurements of the film potential over grounded rollers to detect the charge on a single surface.

DISCUSSION I

***Leaders*: C. Estrada,** Dupont Company, and **P. Pagilla,** Oklahoma State University, USA

Name & Affiliation	Comment
Karl Reid, Oklahoma State University	There are at least two more questions for our last speaker.
Name & Affiliation	**Question**
Jim Dobbs, 3M Company	Your recommendation is to make sure the first roller wraps the inside of the unwinding web. Many unwinders unwind clockwise and counter-clockwise. What suggestion do you have for the machine designer?
Name & Affiliation	**Answer**
Kelly Robinson, Electrostatic Answers	You must allow multiple thread patterns.
Name & Affiliation	**Question**
Dilwyn Jones, Emral Ltd.	I think your presentation was pretty good on understanding the unwinding roll in isolation, but very often there is metal work around. There are certainly going to be side frames and cross-members nearby. What effect do those have on both charging and on your attempts to neutralize the web?
Name & Affiliation	**Answer**
Kelly Robinson, Electrostatic Answers	The rule of thumb is that this ionizer has to be the closest grounded object to the unwinding roll. A machine frame or a crane or other materials nearby will compromise the performance of the ionizer. You have to locate the ionizer in a location where it literally is the closest grounded object to the unwinding roll.
Name & Affiliation	**Comment**
Karl Reid, Oklahoma State University	I was talking to Dr. Brandenburg during the break about asking questions; about having discussion. Years ago when I was involved with the American Society for Mechanical Engineers, as a young professor I saw much discussion occurring at times like this. People coming forward and saying I would like to add some value to what's been discussed; I would like to challenge what has been presented. Sometimes the challenge is more important than the papers themselves in the final print. We are recording questions and answers and as you saw the proceedings of the conferences over the last 20 years, you will see questions and answers in those proceedings. That enriches the proceedings. You are taking away with you proceedings, but the book will be much richer than what you are taking away with you because of the questions and answers. How many of you have never been to an auction? An auctioneer who was very good said that if you have not been to an auction before you don't really understand what the spirit of what an auction is. What we want you to do is get engaged in the spirit of this auction or we're not going

to accomplish our task. What am I going to get bid for this ten dollar bill? (Tim Walker bids $5.00 and wins.) We would like to invite those of you who would like to add something to the day's portfolio to come forward and do that right now. Make your comments about something dealing with what has happened today. Please come forward.

Name & Affiliation	Comment
Kelly Robinson, Electrostatic Answers	The comment I wanted to make is that I was looking at the presentations earlier and it was really interesting to be reminded about how the webs wrap around rollers and when are they in intimate contact and when do they lose contact and experience microslip. I think about this from an electrostatic perspective and I know when I take roll and rub really hard against amber, I get more charge. Whenever I see words like microslip of a web over a roller I think about static. So it is interesting to see the connection between the mechanical properties of microslip and what do we do about it? Where does charge come from and how do we get rid of it? So that insight is valuable to me and I wanted to thank you for it.

Name & Affiliation	Comment
Dave Roisum, Finishing Technologies, Inc.	I came in late and heard about tension and baggy web measurement and some paper processing and I thought it was great. I think one of the greatest challenges in the industry is baggy webs. I think the biggest may be caliper variation that drives baggy webs in the film industry. But in industry, measurement is common to both whether you make them on the paper machine or thick spots on film extruder, it adds up to the same. We need more measurements that are online and affordable. That's my opinion.

Name & Affiliation	Comment
Ron Swanson, 3M Company	We are very low on papers from industry. I didn't offer a paper this time. It is a trend I noticed right away.

Name & Affiliation	Question
Kelly Robinson, Electrostatic Answers	Why is that?

Name & Affiliation	Comment
Tim Walker, TJWalker & Associates	I wrote two papers this time, but I submitted them late so I wasn't on the official program. I probably put in 40 hours of work to make a 25 minute presentation tomorrow. That is one of the answers. I didn't count the experiments that went in behind it and the number of hours there. I am lucky because the work we did was public and there was no approval required to share the paper. There are about 3 reasons right there. The question I want to present concerns tension control work and the work on the disturbances in tension control. I personally haven't solved a problem that was due to eccentricity or runout. I would be interested to

	hear from people who have experienced problems due to eccentricity or runout.
Name & Affiliation	**Comment**
Bob Lucas, Winder Science	In Frederic Parent's presentation concerned with the detection of baggy webs there was sliding shoe of Teflon in contact with the web. I would expect in an industrial application the Teflon will erode due to friction from the web. Then the geometric shape of the shoe is lost and differs from the shape of neighboring shoes. We tried such measurements at several thousand feet per minute and the device totally changed its shape. Working at 50 feet a minute may be one thing but do not be surprised to see the erosion of the Teflon increase at high web speeds.
Name & Affiliation	**Question**
Kelly Robinson, Electrostatic Answers	Couldn't you make a similar measurement with rollers on ball bearings?
Name & Affiliation	**Answer**
Bob Lucas, Winder Science	To be sure and it has been done. Dover Flexo Electronics and others offer such rolls.
Name & Affiliation	**Comment**
Frederic Parent, FPInnovations	Our tool was designed to be mostly a laboratory tool. It was not designed to be in contact with the web all the time. It would destroy the profile of the Teflon sectors.
Name & Affiliation	**Question**
Marko Jorkama, Metso Paper	Does anyone know of a paper that is studies the influence of the tension cross-direction profile before and after slitting? There are internal stresses in slitting that have a great influence. For example a wide web before the slitting section is the entire sheet width but after the slitting section it can be 24 individual sheets. Before slitting, there are residual strains or stresses that are relaxed when the web is slit. That creates problems because some individual sheets can become very loose and others very tight. Are there any studies about this problem?
Name & Affiliation	**Comment**
David Wager, DuPont Teijin Films	I wanted to comment on some previous queries. The first is with regard to these tension changes and fluctuations being measured across the web width. The tension variation can be used to infer web length variation across the web width. This can cause problems at various locations in a process line, for example, you may have a thin non-uniform length web entering a nip roller. This film can be very sensitive to small changes in that nip due to the tension variation going into it. The second comment I would like to respond to regards why there are fewer papers from industry? It could be a problem with confidentiality. Often our work is extremely confidential and we cannot share it in a public domain. That's really unfortunate. Maybe in the future when some of this work becomes old hat we can share it. My third comment is that often at these conferences we

discuss being able to wind or handle film better and how we are altering our equipment to try to improve that situation. I believe we need to discuss making the film or web more uniform in thickness, length and perhaps properties to make it easier to handle in our machines and our customers machines.

Name & Affiliation	**Question**
Prabhakar Pagilla, Oklahoma State University	Prof. Brandenburg: You talked about slip and tension models and how hard it is to quantify slip and incorporate it into tension models. Can you discuss the effect of variable slip? The microslip wrap angle is now changing dynamically, how would one incorporate that into tension models? We have differential equations for tension, algebraic equations for the slip, what is the best way to incorporate these equations into model simulations?
Name & Affiliation	**Answer**
Günther Brandenburg, Technische Universität München	If the tensile force varies, the angle of wrap where slip occurs also varies and your question regards what influence this has on web dynamics. The models which I have developed are linearized models and they are valid for one steady state operation point only. We say there is a steady state and from this steady state, we introduce small perturbations. These perturbations may change the angle of wrap a little bit and the result is not visible because of the linearization. I think you must simulate the nonlinear equations correctly before you will find some result on the tension in the web section. Also if you have webs where the lengths of the free web spans are comparable to the lengths of the sliding zone on the roller: You have a time constant of the free web span and you have a time constant of the area of slip and these both time constants add to yield the resultant time constant of the system in the span. Mostly long web span are assumed but if the web becomes shorter and the zone of web slip on a roller is comparable to this length, there will be an effect on the dynamics of the complete system. I have shown this in my dissertation.
Name & Affiliation	**Question**
Prabhakar Pagilla, Oklahoma State University	What about 2 dimensional slip, both circumferential and lateral? John Shelton considered this, maybe he has a comment?
Name & Affiliation	**Answer**
Günther Brandenburg, Technische Universität München	When I developed the first theory in 1971 I assumed that the lateral contraction coefficient of the web was zero because I didn't dare deal with these 2-dimensional frictional problems. The time was not mature for such problems. I was very content to have a simple model with which the main tendencies of the web dynamics could be described.

Name & Affiliation	Comment
John Shelton, Oklahoma State University	The effect of friction on web behavior is a nightmare. We assume Coulomb friction models that are not realistic. Measurement of frictional behavior is difficult. If you have some model that gives you worthwhile results, you use it instead of complicating it. Coulomb friction is usually better than nothing.
Name & Affiliation	**Question**
Karl Reid, Oklahoma State University	Prof. Brandenburg gave us a list of topics that related to tension effects on the longitudinal motion of the web. What typical problems do you have that you have witnessed other than the ones he listed that are important to you?
Name & Affiliation	**Answer**
Cal Estrada, DuPont Company	We have tension control problems for high value webs where very low tensions can damage fragile coatings. We handle nonwovens which have directional properties, and if you have misaligned rollers there will be too much tension in one direction. We have lots of problems with transporting webs at very low tension.
Name & Affiliation	**Comment**
Gary Strike, WebTech Omega, LLC	Any tension variation is going to affect registration. If tension isn't controlled you are going to have variation in the location of components placed on webs. These are some examples.
Name & Affiliation	**Comment**
Unknown	Part of the problem we witness in the experimental data is that you have so many influences and you have to extract the data which are important. This is a difficult discussion with production people; they don't care about tension control as long as the product can be sold. A good point was made earlier; you have to consider the customer. If the customer has a problem with the web, they will complain. Normally there will be very little time to solve a problem. When you review the measurement data you see much too much and you don't have time to analyze and understand everything. My experience is normally we don't have good enough instrumentation in the web line. In the experimental data we saw here, in the display there was over 100 seconds so the time resolution was maybe about 1 Hz. We know to get good information regarding dynamic behavior you have to capture data at much faster update rates – maybe 100 Hz, maybe faster. It is difficult to measure tension with a frequency content up to 100 Hz. There is not much equipment which will allow us to do that. We know the dynamics of a fast machine with the high angular velocities will be in this range. Most people will know they have a tension problem, but it is very hard to tell what the source of the problem is. The problem might be the eccentricity of the roller, a control problem or an equipment defect. Each problem can be solved with a very

	delicate control or by changing equipment. Normally, we don't have this information so you just start changing things until the problem is eliminated. The problem is not really solved in a way that we as engineers would like. We like to know the reasons. Many problems are solved by changing control or equipment, but why the problem was solved and why it returns is not understood.
Name & Affiliation	**Comment**
Dave Roisum, Finishing Technologies, Inc.	I think position error is more important than tension error. If you have a long span that has a tension oscillation you have a huge displacement which is a problem for registration. The same is also true for the cross-direction position; so long spans are really bad for both MD and CD registrations. Another extreme is a central impression printing press. There is absolutely no movement because we lay the web on a surface and all subsequent printing is performed while the web is locked onto that surface. So I think if you start to think more about position instead of tension, you can understand more what the customer is concerned with. I would first say that short spans are desirable and then after you have the shortest spans possible, work on tension systems.
Name & Affiliation	**Comment**
Tim Walker, TJWalker & Associates	What I often tell people in training is strain is the secret to web handling. In many cases, I don't care about the tension, but I do care about the strain in the web. Everything you look at – roll diameter variations, roller alignment, wound roll defects – strain will help you understand why the defects are happening. I wonder about the tension variations from eccentricities. If it's a stiff material and you have a 5% tension swing the strain change is so small it is below the registration error people complain about. I'm not talking about a low stiffness web where a 5 pound tension oscillation will cause large registration errors. In fluid bearing coating methods where the web tension affects coating thickness a 5% tension variation will be evident. As far as wrinkling or winding, is anyone going to care about a 5% tension variation?
Name & Affiliation	**Comment**
Bob Lucas, Winder Science	I agree with the comment on strain and it has been my contention within winding processes. If you were only to look into speed differentials and displacements and the like as opposed to torques, tensions, and forces. The torques, tensions and forces are easy for us to measure. The strains help us understand the viscoelastic and dynamic response of the web. My thoughts are not focused on web tension control but trying to understand what happens to webs in the nip. Strain is everything.

Name & Affiliation	Comment
David Wager, DuPont Teijin Films	This comment is for our machine builders. Maybe we should be thinking about designing diagnostics into our machines from the very start. Now the dilemma, of course, is if you start doing that it can increase equipment cost. All the machine suppliers will compete with each other and drive the cost down. Maybe it would be a good selling point. You could attend a conference such as this, decide what diagnostics to incorporate to solve web handling and processing problems. This would prevent those that buy your machinery from running offline tests on production samples. You could allow your customer to troubleshoot problems on the machines they are running. That's a thought for the future.

Name & Affiliation	Comment
Günther Brandenburg, Technische Universität München	Is it worthwhile to have models because the development of models is a question of time and money? When I began this research in approximately 2000, we investigated a commercial printing press and my keynote was about this field. Some people said the model is fine but the people running newspaper printing presses said you can forget your models because the presses are always floating. You have some tension, you have some strain, you have whatever. Then we had the opportunity to take measurements in the newspaper machine. We thought OK, let us measure the time constants of some friction. We measured it and we received results which were by factor 3 slower than the calculated time constant of the section. This was very interesting because people are inclined to say this is the difference between theory and practice. Forget your theory because we built the machine and it is as it is. Then we tried to get more information on this effect and what we found was that the drives were very soft. That means the control of current speed, this was a speed control drive, was too slow. The drive was very sluggish and then we increased the amplification factors the controllers and we superimposed on a drawing roll and angle control, which is not normal. Then you get a very stiff drive; then we succeeded in measuring exactly these time constants which we have calculated. This was very surprising. We ought to mention that the paper machines are something different from the commercial presses is not really true. There are many, many effects which we cannot model, I must admit it, but a good model is worthwhile to have because you can explain fundamental properties of some phenomenon and you have a deep insight into the physics of the process. So without doubt, for me it is a good model, a good help for the practicing engineer.

Name & Affiliation	Comment
Clarence Klassen, KlassEngineering	I work on tuning drives, the speed regulators, the torque regulators, the tension regulators, and we do not have a lot of industry-wide knowledge about how they are tuned – the bandwidth for various regulators. I know what I did with the company I worked for. I hear rumors of what people want and what they are getting in other industries. I see equipment tuned by others and I see a wide spectrum of performance – very wide. I don't think we have any numbers industry wide for how drives are tuned. Different drive vendors have different methodologies for tuning their drives, as well, which isn't helping.
Name & Affiliation	**Comment**
Prabhakar Pagilla, Oklahoma State University	Another comment that came up is that if machine builders were to incorporate diagnostic tools, what would the users like to see in those tools? Prediction of tension because you don't have load cells in certain areas? Things like that? What would you like to see?
Name & Affiliation	**Comment**
David Wager, DuPont Teijin Films	Load cells are just one item, but there could be other measuring devices as well. One of the things that affects us quite seriously often is vibration in the machine. We are looking for vibration sensors. I think when machine builders actually come up with our initial design and layout, there ought to be a degree of analysis from the very start; some kind of prediction in modeling of its behavior before we even get started on actually producing that machine. We will have our own ideas of how a machine should look and its preferred layout and some spans it's actually good to have a long length. For some processes it is good to have short spans. Maybe more modeling should be done by suppliers as well as diagnostics. If you think about all the kits that you have on your machines - pilot lines, test plots, etc. - some of that could be built into the machine that might help. They don't have to necessarily be part of the machine supplied but they could be options. The interesting thought is that customers are all wanting to try to optimize their machines process could so from the start.
Name & Affiliation	**Comment**
Tim Walker, TJWalker & Associates	Data trending is important for me, web tension from load cells for example. Web position is another measurement you don't see trended very often. Monitoring web width is a great tension indicator on certain webs. You infer tension from web width. One of the problems of diagnostics is equipment designers don't always have that much experience running the equipment or processes. They know it sells, but if you see how many hours they have actually spent running their own equipment, they are pretty limited. My advice is you hire someone who really knows web handling and have them come to review the equipment.

Name & Affiliation	Comment and Question
Bob Lucas, Winder Science	I'll state a situation and then I'll ask a broad question regarding how much modeling you want. We had within our company an application with a winder after a coater and it had to operate at high speed. The drive supplier could not make it work. We had a fellow in-house who was very good at modeling machine dynamics and drives in a process machine. He modeled the whole region of the machine. He was able to solve the problem but he ended up with 3rd, 4th, 5th order lead and lag circuitries in the drive which the drive supplier was not able to provide and maintain in the field. It required a lot of time to complete this analysis, but it was required to keep the product line working and the customer happy. Is this something the industry is going to expect and if so, what cost levels are they willing to absorb to have someone who is proficient to model the machine? Should we expect to perform a transfer function analysis on every component in a machine?
Name & Affiliation	**Comment**
Gary Strike, Webtech Omega, LLC	During my presentation I discussed base case modeling. The base case is modeling only those parameters that are of interest. Modeling would start with just a few parameters which dominate behavior. Usually the unwind roll or a similar component with the largest inertia will be the dominant factor in a system. If you have a high stiffness web, if it's not a stretchy material, it doesn't have to be considered in the model because it is all one continuous system. In my paper you will note the K_e web span system which includes the input roller and the output roller. The rollers have velocity control systems that are complete PI controllers. The whole system is detuned so you have the effects of the web tension on each side of the roll, which affects the roller velocity. You would not design a system like the base case, but to Dr. Brandenburg's point you have insight to the parameters and you know what is affecting your system. That's what is important, from there you can design and tune a real system with that insight.
Name & Affiliation	**Comment**
Jim Dobbs, 3M Company	I have a follow on Tim Walker's comment on tension load cell instrumentation. I don't know that we need more instrumentation on machines. I think we need better ways to review the information that those instruments are telling us already. For example, you can observe a needle on an analog indicator or a digital display of the output of a tension load cell but it doesn't tell you much. Why not harness the power of computers and digital electronics we have and provide real time output of what the disturbance frequencies are? We can learn to associate those frequencies with rollers, unwinding rolls, broken machinery, etc. A control system must fight these

	disturbances. If you know what the disturbance is you should eliminate it if possible. It is great to have a robust control system that will handle disturbances gracefully, but disturbance elimination should take first priority. We need better diagnostics for using the information that is already available from these machines. Process machines have many sensors, controls, and a lot of computer power to record the data. Most of that data is unused. We need well thought out information digesting systems to give the engineers and operators directives that the disturbance is at roller number three which happens to be at the end of the oven. Perhaps the bearings have failed due to the oven temperature and need replaced. A smart operator would figure this out through time but good diagnostics could pinpoint the disturbance immediately.
Name & Affiliation	**Comment**
Dave Roisum, Finishing Technologies, Inc.	I agree that we do not necessarily need more measurements. There are paper mills that gather data from many sensors at sampling rates of over 1,000 Hz. Maybe they are trying to assess whether they have a good lot or a bad lot or a good roll from a bad roll. I believe time based samplings are absolutely worthless.
Name & Affiliation	**Comment**
Karl Reid, Oklahoma State University	How do you know when your product is not a good product? Do you get a call from the customer? What does the customer say? What is wrong with your product? Sometimes the customer is right and sometimes they may be wrong. Your challenge is to demonstrate to the customer whether the problem may be a machine problem or a process problem. This leads to an open ended question of how do you know when you've produced a good product? That has been an undercurrent throughout the discussion this afternoon.