MACHINE AND TRANSVERSE DIRECTION ERRORS IN WEBS: DIAGNOSIS AND REMEDIES

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ABSTRACT

The primary focus of web handling is often on tension control; however, equally important to almost any web handling or winding process is to maintain machine (MD) and transverse direction (TD) control of the web. This paper outlines a guide to loss of control or position of the web in both the machine and traverse direction on in handling over rollers or winding rolls. For each category of MD/TD errors in handling/winding, this paper covers: measurement, problems, root causes, and solutions tailored to each specific mechanism. This paper is not seeking to review the equations of traction or lateral control, which have been covered in many previous works, but to focus on the common problems of MD and TD control and target appropriate solutions.

CATEGORIES OF MD AND TD ERRORS

1. MD Slip of Web on Driven or Idling Rollers
    a. Low Traction Available
        i. Unnipped Rollers
        ii. Nipped and Vacuum Rollers
        iii. Air Lubrication
    b. High Traction Requirement
        i. Idler Roller Performance
        ii. Tension Change Across Zones
2. MD Slip of Layers in Winding or Unwinding Rolls
    a. Center Torque Cinching
    b. Inertial Torque Cinching
    c. Core Layer Tightening
    d. Internal Gearing
3. TD Slip or Shifting of Web on Rollers
    a. TD Slippage
        i. Micro-Slippage of Tension Change

        ii. Insufficient Bending Force
        iii. Mismatched Speed
        iv. Excessive On-Roller Spreading
    b. TD Offset or Oscillation
        i. Initial Position Error
            1. Unwinding Error
            2. Threading Error
        ii. Transport Error
            1. Misalignment
            2. Diameter Variations
            3. Asymmetric Web
            4. Uneven Nipping
            5. External Forces
        iii. Web Guide Error
            1. Poor Tuning
            2. Excessive Input Error
            3. Poor Guide Geometry
            4. Sensing Delay

4. TD Slip or Shifting of Layers in Winding or Unwinding Rolls
    a. Web Shifts Prior to Winding Roll (See the previous three sections.)
    b. Layers Shift within the Winding Roll
        i. Air Lubrication Telescoping
        ii. Cinching-Related Telescoping
        iii. Deflection-Related telescoping (usually only slit rolls)
    c. Core shifts relative to roll during winding
    d. Pressure Sensitive Adhesive Telescoping
    e. Layers Shift in Roll Handling or Storage
    f. Layers Shift within the Roll during Unwinding

MD SLIP OF WEB ON DRIVEN OR IDLING ROLLERS

Definition. The web has a machine direction velocity faster or slower than the surface of a driven or idling roller, whether over all or part of the web-roller contact.

How to Measure. For driven rollers, monitor the speed of any two driven rollers. If one driven roller runs faster or slower than another driven roller by a percent outside the reasonable strain of the web, one of the rollers must be slipping. Idler roller slip is rarely measured, but a simple handheld contact tachometer can be used to check for web vs. roller surface speed differentials. Optical tachometers can monitor idler roller speeds without increasing roller drag.

Problems of MD Slip on Driven or Idling Rollers

✓ Scratching, abrasion (of web or roller), debris
✓ Loss of speed control (causing coating variations in flow metered coating methods and many other length / speed related defects)
✓ Loss of tension control
✓ Loss of parallel entry rule, leading to:
  o Loss of control in steering and displacement type web guides.

- Loss of outward displacement mechanism on good traction, diameter-based spreaders (tape collar roller and concave rollers), leading to gathering or wrinkling.
- Loss of outward displacement mechanism on good traction, misalignment based spreaders (bowed, flat expander, and flex expander rollers).

Mechanisms And Root Causes	The tension change across a roller exceeds the traction available. The Traction Safety Factor (TSF) is defined as the available traction divided by the traction required. Traction required on idler rollers will vary with low vs. high speeds and accelerating/decelerating conditions. Traction required for driven rollers depends on the tension change between upstream and downstream tension zones. If the TSF is less than one, the roller will have MD slip. For any roller with a tension change, there will be a micro-slip zone on the downstream side of the roller wrap angle. The micro-slip zone angle is governed by the belt equation and dependent on web-roller traction coefficient and tension ratio in-to-out. The length of the micro-slip zone will increase with roller diameter. Under slip conditions, an idler roller may slow down or stop. If the applied traction is below what is needed to overcome break-away drag, the roller will stop. If the applied traction is above the break-away drag, but below the traction required to run at web speed, the roller will turn at a speed governed by the balance of applied torque and increasing torque of speed or acceleration rate. A speed controlled roller programmed to run in a draw that exceeds the traction force required to strain the web will run at the set speed ratio, but slip relative to the web. A speed controlled roller in closed-loop tension control is often programmed to run the speed of the line master section plus or minus a set percent (often 10 percent). If slipping, the driven roller will run to it maximum trim at running ten percent faster or slower than the web. If the master drive roller slips, it will run at set point, but the web will run faster or slower as one of the non-slipping follower driven roller becomes the default line master. **Traction Available** **Unnipped Roller.** The traction of a tensioned web wrapping an unnipped roller is a function of coefficient of traction, web tension (in force per width), web width, and wrap angle. The lateral friction available is a simple product of these factors, but the machine direction traction is governed by the belt equation. The belt equation takes into account how machine direction sliding friction from micro-slip between web and roller will alter the tension as a function of

wrap, making the traction available increase or decrease from the non-slip value. The belt equation does not enable any absolute traction level, but states the traction limit as a ratio of incoming to outgoing tension.

The *coefficient of traction* is the same as the coefficient of friction when air entrainment is insignificant. As the entrained air layer grows to a height approximately equal to the combined roughness of the web and roller, the web-roller interface will begin to lubricate. The 'apparent' coefficient of friction (now called the coefficient of traction) will decrease as the entrained air layer height increases and until the web-roller interface is swimming in air and the coefficient of traction is essentially zero.

Nipped Roller. The traction created by two rollers nipping the web is a function of the web-to-roller coefficient of friction (COF) and the total load exerted on the web. There are three different COFs that may determine the friction limit in a nipped roller system: the COFs of web to roller A, web to roller B, and roller A to roller B. In the case of a thick web where the nipped roller does not make contact outside the web's width, the roller to roller COF does not apply.

In the case where the web is thin and one or both of the rollers conforms or deflects around the web to make contact outside the web width, then the roller to roller COF may be important. For the web to slip in this thin web case, two of the three contacting combination must slip. Either the web must slip relative to both rollers or the web and one of the rollers must slip relative to the other roller.

Vacuum Roller. For a vacuum rollers (a.k.a. suction rollers), the friction created from tension over a wrapped roller is supplemented with the friction created by net pressure created by evacuating air from the inside of the porous or perforated roller. Friction from the suction roller's pressure drop will increase with web-roller coefficient of friction, the belt effect of wrap angle, and normal load created from the effective pressure drop across the web and the total effective area exposed to pressure drop.

Note: The effective pressure drop is the difference from atmospheric pressure and lower pressure between the web and roller, not the suction roller's internal pressure. This difference is dependent on the pressure loss through the roller's shell, which is a function of suction roller design. Also, the effective area exposed to the pressure drop will increase with web width and wrap angle, but does not equal the total roller contact area. The web only feels the suction roller pressure drop in the area controlled by the hole or groove pattern.

Traction Demand

In this case, instead of viewing drag and inertia from a series of rollers, consider the drag and inertia from a single roller. The solutions to reduce tension losses from drag and inertia apply here as solutions to keep the traction demand for a driven roller low.

To determine the traction demands of a driven roller, first consider the nominal tension differential created by the tensioning systems in

	the upstream and downstream tension zones. In the case of closed-loop tension control, the nominal tension is the value measured by the load cell roller or created by the dancer roller pushing into the web. Take care to ensure load cells and dancer rollers are calibrated to verify they are creating or sensing the desired tension set point. Be careful with open-loop torque systems to verify they are applying the desired value. In the case of torque controlled tensioning, the nominal tension is the applied torque divided by the roll or roller radius (with all the potential errors of torque system listed above). In the case of draw control, the nominal tension is set by the baseline strain of the web entering the draw zone and the change in strain created by the positive, neutral, or negative draw (with all the potential errors of draw control systems). To find the traction demand across a driven roller, start with the nominal upstream and downstream tension (and the errors listed in the previous paragraph) and add to this nominal zone-to-zone differential the additional tension change within the upstream and downstream zone due to all the factors included in the 'Tension Varies Within a Zone' discussion. Traction Safety Factor will drop below one due to: **Traction available is too low:** 1. Tension-induced friction (non-lubricated) decreases with lower web-roller coefficient of friction, wrap angle, and tension. 2. Nip roller loads or effective vacuum roller pressure and area are too low. 3. Entrained air exceeding combined web and roller roughness, texture, or porosity. **Traction demand is too high:** 1. Traction requirement increase with increasing torque from poor roller performance and inertia during acceleration or deceleration. 2. Traction requirement on drive rollers increase with tension changes from zone to zone. Solutions to each of these machine direction traction limits are covered below.
Solutions To Low Tension-Induced Friction	1. Increase tension in the entire tension zone (increase air to dancer roller, set point for load cell feedback, torque to clutch or brake, speed ratio). 2. Increase friction coefficient by covering, wrapping, or replacing a roller to have a higher COF to web. 3. Increase tension locally by adding or removing drag or inertial losses from idler rollers within a tension zone. To increase tension on the upstream end of a tension zone, reduce roller drag. To increase tension on the downstream end of a tension zone,

	increase roller drag. 4. Increase wrap angle on rollers by adding idler rollers or changing the threading order of existing rollers. 5. In wrap-limited systems (e.g. support rollers in an arched web path oven), remove rollers to increase wrap angle on remaining rollers. 6. Use positive or negative air pressure to increase the catenary sag between rollers and increase wrap angle. Use Coanda effect near rollers to create negative pressure and increase wrap angle.
Solutions To Low Nip Or Vacuum Roller Friction	1. Increase nip roller load or coefficient of friction between web and driven roller. 2. Increase roller conformity around web with larger diameter, thickness rubber covering, and lower Durometer hardness. 3. Increase load on web by minimizing deflection and width of nipping rollers outside web width (for thin webs). Ensure mechanical stops, if present, do not restrict load applied to web. 4. Increase wrap angle, diameter, or effective vacuum exposure area of vacuum rollers.
Solutions To Entrained Air Exceeding Roughness, Texture, Or Porosity	1. Reduce entrained air with decreased radius, speed, and air viscosity and increases with tension or nip load. 2. Increase web roughness through substrate manufacturing process (slip additives, quench or calendar roller roughness) or post-processing (coating, patterned printing, embossing, scratching, knurling). 3. Increase roller roughness by higher machined roughness, sandblasting, plasma sputtering, ceramic coating (rough), or wrapping with a material of increased roughness. 4. Increase porosity of web by perforating. Increase roller surface porosity by holes, perforation, or air-absorbing wrap material (e.g. cheesecloth, felt). 5. Reduce air lubrication locally with crossweb tension variations induced by misalignment, diameter variations, or baggy web. In each case, lanes with above average tension will maintain traction longer than a uniformly lubricating cylindrical roller.
Solutions To Poor Roller Performance And Inertia Losses	1. Idler drag – Reduce bearing drag with fewer rollers, smaller diameter bearings, non-contact seals, oil or liquid grease lubricant (eliminate Zerk fittings), proper assembly to avoid side loading, proper sizing of elements or spherical bushing/bearings to avoid excessive torque loads, lateral freedom to avoid thermal expansion loads. 2. Idler inertia – Reduce inertia with fewer rollers, smaller roller diameters, and lower mass rollers (minimize diameter, wall thickness, width, and material density). Reduce inertial torque by reducing acceleration and deceleration rates.

Solutions To Zone-To-Zone Tension Changes	Reduce tension changes between zones. 1. Change tension set points, torques, or draws to create even tension into and out of drive rollers. 2. Reduce loads on the web that create tension changes within tension zones, including roller drag, inertia (during acceleration), and slipping elements. 3. Place feedback devices near driven rollers to minimize confusion (at least on one side) of what the input or output tensions are. 4. When large tension changes are required, use multiple driven rollers to reduce the tension change over any one driven roller.

MD SLIP OF LAYERS IN A WINDING OR UNWINDING ROLL

Definition. The torque applied between some or all layers within a wound or winding roll exceeds the traction available to transmit that torque (a.k.a. torque capacity), causing layers to slide in the direction of the applied torque.

Though cinching can occur at winding or unwinding and in the tightening or loosening direction, the most common cinching is the tightening direction at unwinding, usually starting in layers near the core.

MD slip in winding rolls is more difficult to measure. An inkjet printer synchronized with the winding roll will form a spoke line (no slip) or D-line (indicating MD slip).

Problems of MD Slip of Layers in a Winding or Unwinding Roll

✓ Scratching, abrasion, debris
✓ Loss of tension control
✓ Roll tightness increases or decreases
✓ Cinching-induced telescoping
✓ Crepe or cigar wrinkle in paper winding

Mechanisms and Root Causes	**1. Center Tensioning Torque Cinching** A roll’s torque transmission capacity is calculated throughout a roll by multiplying any layer’s internal radial pressure by its area of contact, side A-to-B coefficient of friction, and radius. In center winding or unwinding, the torque is applied to the roll from its center to create tension at the roll’s outer diameter. The onset of cinching related telescoping is most commonly seen as a roll grows in diameter and first appears in the layers near the core and the outer wraps. Many winding tension profiles use constant or moderately tapering tension vs. radius, requiring more torque at larger diameters. The cinching onset begins near the core since these layers have less area and are at a mechanical disadvantage to the outside of the roller (creating a radius-square effect, with outer layers

having more torque capacity).

The relationship of tension to pressure is non-linear. A small increase in tension can greatly increase torque capacity. Gauge bands can create lanes of high internal roll pressure and increase average roll pressure. A roll with a flat thickness profile will have less torque capacity than a roll with gauge variations.

Thick, low friction webs are the most prone to cinching-related telescoping. Rolls winding with low initial strain due to high spring constants (high modulus and thickness) can more easily lose their inner layer tension from compression of the core or inner roll layers.

2. Inertial Torques Cinching

During acceleration and deceleration, inertial torque is transmitted through the roll. In center winding or unwinding, the inertial torque is opposed by the center drive. In surface winding or unwinding, the inertial torque is opposed by the surface drive.

Unwinding, loosening/tightening cinch: If you aggressively accelerate a large unwinding roll from its core the outer roll layers act as a flywheel opposing this speed change. The layers near the core will accelerate faster than the roll's outer layers causing a loosening cinch. With aggressive deceleration, the opposite happens, tightening the roll.

Center winding, tightening/loosening cinch: If you aggressively accelerate a large winding roll from its core the outer roll layers act as a flywheel opposing this speed change. The layers near the core will accelerate faster than the roll's outer layers causing a tightening cinch. With aggressive deceleration, the opposite happens, loosening the roll.

Surface winding, loosening/tightening cinch: If you aggressively accelerate a large winding roll from its surface the inner roll layers act as a flywheel opposing this speed change. The layers near the core will accelerate slower than the roll's outer layers causing a loosening cinch. With aggressive deceleration, the opposite happens, tightening the roll.

3. Core Tightening Cinching

Core tightening cinching can be a defect with a viscous cycle where the onset of the defect creates more of the defect. If unwind center tensioning cinching causes the layers near the core to tighten, these layers will move to a small radial position, falling away from the outer layers of the roll. This radial contraction reduces the pressure between layers outside of the contraction zone, reducing their ability to transmit center torque, causing the cinching zone to expand to layers further from the core.

4. Internal Gearing

In center winding and unwinding, the roll's weight is supported on the core. The load of the roll's layers hanging over the core forms a high pressure area at the top side of the core (12:00 position) similar to a nip roller. As the roll rotates, the layers entering the high

	pressure zone will compress and elongate, rejecting some material like a nip roller. The excess material may fold over inside the winding roll.
Solutions to MD Slip in Rolls	1. **Center Torque Cinching**. Increase the winding roll's torque capacity: (All these solutions will help both winding and unwinding cinching. *Solutions specific to help unwind-cinching after storage are in italics)* ▪ Increase tension, especially near the core (consider 'hard start') ▪ Increase friction coefficient ▪ Increase area and reduce the mechanical disadvantage of layers near the core with larger core diameter~~.~~ ▪ Increase crossweb thickness variations (including induced thickness variations from printing, coating, or knurling)~~.~~ ▪ Minimize core compression or shrinkage, including manage *paper core moisture content to ensure cores are dry*, use a core with sufficient stiffness for the internal roll pressures of your product (consider shifting to stiffer core) ▪ Minimize shrinkage of layers, including substrates, coatings (including lateral flow of viscoelastic coatings, like adhesives), roughness or texture, and entrained air~~.~~ ▪ Decrease the applied center tensioning torque by reducing final diameter or final tension / more taper tension (both for center driven winders) or switch to surface winding. 2. **Inertial Cinching**. Decrease the applied inertial torque by reducing final diameter or accel/decel rates. 3. **Core Layer Tightening Cinching**. Stop even the smallest amount of cinching to prevent core tightening-induced cinching. 4. **Internal Gearing**. Decrease roll buildup ratio, especially with increased core size. Increase near core roll tightness. Switch to surface winding with winding roll supported from below. Minimize rotation while supported from the core.

TD SLIP OR SHIFTING OF WEB ON ROLLERS

Definition. TD slip or shifting is a change in the web's lateral position as it runs through a process or on a roller. TD slipping or shifting is divided into four categories.

1. The web slips laterally while in contact with the roller.
2. The web runs helically around a roller, leaving a roller in a lateral position different from where it entered.
3. The web makes a consistent lateral shift as it runs in the span between rollers.
4. The web oscillates or wanders laterally as it runs in the span between rollers.

Only in the first case does the web have to slip relative to the roller's surface. TD slippage is the lateral motion of any single point of the web relative to its initial point of contact on the roller during the angle of contact. If MD slippage occurs (see above), TD slippage is also likely. TD slippage can be defined to occur when the web fails to follow the parallel entry rule. TD slippage can also occur on the exit side of roller contact in the micro-slip zone on rollers with low to high tension changes.

In the second case, the web seems to change it position on the roller, but this is an optical illusion much like the ‘motion’ of a stripe on a barber’s pole.

How to Measure. Draw a line on the roller where the web edge runs and note if the web moves relative to the line. Use an edge sensor or line sensor from an automatic web guide to monitor the web’s lateral position. Monitor an automatic web guide actuator motion to determine the shifting of the web entering the guide. Measuring the difference between TD slippage and TD shifting can be difficult. A debris particle or burr on a roller will gouge the web during shifting, but create a scratch larger than the particle or burr in slippage.

Problems of Web Slipping or Shifting Laterally (TD)

- ✓ Scratching, abrasion (of web or roller), debris
- ✓ Unpredictable tracking
- ✓ Unpredictable web guiding
- ✓ Failure to spread wrinkle-prone web or slit strands
- ✓ Loss of lateral registration at slitting, coating, printing, laminating, and winding.
- ✓ Lateral bending induced shear wrinkles.

Note: One benefit of webs slipping laterally on a roller – no wrinkles due to lack of friction.

Solutions to Web Slipping Laterally on Roller

Mechanisms And Root Causes	Root causes of TD slippage include: 1. Micro-slippage occurs to a degree on any roller if the web’s strain change exceeds the web’s ability to deflect the roller’s surface. The most significant micro-slippage, both MD and TD, will occur on driven rollers that separate large tension changes. 2. Webs will laterally slip on a roller if the web-roller traction is insufficient to enforce the parallel entry rule, especially at steering roller with short entry spans and sometime displacement guides. 3. A web is highly likely to slip laterally on any roller with a speed mismatch relative to the web, whether oversped, undersped, or stopped. 4. Overly aggressive spreading of bowed roller or flat expander spreaders. These rollers will spread the web in the upstream span, contacting the roll at a full taut width. Any additional spreading during roller contact likely exceeds the web-roller traction available, leading to TD micro-slip and roller abrasion.
Solutions To Micro-Slippage Tension Change	First, the same changes that reduce MD slip from tension change will reduce TD micro-slip. 1. Reduce tension changes between zones. 2. Change tension set points, torques, or draws to create even tension into and out of drive rollers. 3. Reduce tension losses that create tension changes within tension zones, leading to confusion on what actual driven roller tension change is. 4. Place feedback devices near driven rollers to minimize confusion

	(at least on one side) of what the input or output tensions are. 5. When large tension changes are required, use multiple driven rollers to reduce the tension change over any one driven roller. Other solutions include: 1. Use a roller surface that can move with the web, such as a flex spreader roller or cloth wrap.
Solutions To Insufficient Traction To Enforce Parallel Entry Rule.	1. Increase web-to-roller traction (see the previous section for the many causes and solutions to MD slip). 2. Increase span length to reduce traction required to bend the web. 3. Reduce lateral shifting required by web guide by either matching the exit guide point to the entering web's position or shifting the web upstream to reduce the downstream guiding offset (the latter can be done proactively with coordinated guides). 4. Replace short span steering guides with displacement or sidelay guides when correcting a long span is not required.
Solutions To Mismatched Speeds	1. Ensure driven rollers are accurate to within the stretch-ability of the web. 2. Avoid MD slippage (see previous section).
Solutions To Excessive Spreading Roller	1. Avoid setting excessive spreading percents, especially for high elastic modulus webs. 2. Avoid excessive wrap angles on bowed and flex expander rollers.

Solutions to TD Offset or *Oscillating* Shifting *(Oscillating notes in italic.)*

Initial Position TD Shift	**Shifted Layers in Unwinding Roll** – Unwinding roll has shifted layers without unwinding automatic guiding. *Unwinding roll has oscillated layers and no unwinding guiding.* Solution: Ensure unwinding rolls have good sidewall alignment and are correctly positioned on the unwinding core, shafts, and chucks. **Threading Error** – Web walks from initial threading position to running position. Solution: Ensure the web is threaded correctly as close as possible to the web's running position. Avoid unthreading equipment by leaving the process threaded, using a leader or trailer web when the product web cannot be left in the web line.
Transport TD Shift	**Misalignment** – Misalignment of roller, air turn bar, unwinding roll, or winding roll, especially on moving or eccentric elements such as dancer rollers, turret winders, out-of-roll or non-concentric unwinding or winding rolls. *Misaligned roller combined with web-to-roller traction variations causing the web to transitions from stick to slip behavior over time, especially from transitions due to inertia during acceleration or deceleration and from air lubrication as speeds increase.* Solutions: Ensure good alignment of all elements in contact with the web, including rollers, air turn bars, the unwinding roll, or the

	winding roll, especially moving or eccentric elements such as dancer rollers, turret winders, out-of-roll or non-concentric unwinding or winding rolls. Avoid transitions from stick to slip or good to poor traction by ensuring the Traction Safety Factor on all rollers is greater than one for all conditions including acceleration, deceleration, and high speed-to-tension cases. **Diameter Variations** – diameter variations in roller, web on roller, or winding roll. *Crossweb diameter variations changing over time, such as a winding roll.* Solutions: Minimize diameter variations in rollers and winding rolls (especially in free span winding), including diameter variation of a web running with a coating or laminate between it and a roller acting like a diameter variation. **Asymmetrical Web** – Cambered or baggy web, especially in long spans and in air floatation handling. Changing cambered or bagginess in a web, especially in long spans and in air floatation handling, including misaligned splices. Solutions: Minimize web camber and bagginess. Ensure well-aligned splices. **Uneven Nipping** – Crossweb nip variations, especially with tangent entry into nips. *Changing crossweb nip variations, especially with tangent entry into nips.* Solutions: Ensure crossweb uniformity in nipping. Wrap nips with at least 5 to 10 degrees before the nip tangent point (more is better in this case) to create web-roller friction between nip variations in the entering span. **Uneven Air** – Crossweb variations in supply velocity of air nozzles or air turn bar, especially with long spans. *Unstable air supply in air nozzles or air turn bar.* Solutions: Minimized crossweb variations in supply velocity of air nozzles or air turn bar, especially with long spans.
Guiding TD Shift	**Poor Tuning** – Automatic guide PID loop is poorly tuned. Solution: Ensure web guide actuation rate and system gain is as high as possible and any actuation slop or measurement dead band are minimized. **Excessive Input Errors** – *Web walks on downstream roller from upstream source of lateral oscillation.* With automatic guiding, unwinding roll or input web has lateral step change *(or oscillation)* exceeding automatic guide's range or rate limits. Solution: Minimize lateral errors starting at the unwind and working through the process to ensure good alignment downstream. Avoid exceeding automatic guides range. Center the web errors within the automatic guides range. If an unwinding roll is known to have shifting that will exceed an automatic guide actuation rate at normal process speeds (such as handling related telescoping), reduce the line speed when the unwinding roll gets to the high rate error layers to keep the error rate with the guide's actuation rate.

	Guide Geometry – Web guide geometry is non-ideal. Automatic steering guide has under- or over-steering geometry, especially with unstable entry to pre-entry span ratio. Solution: Follow the recommended geometry for displacement and steering guides. Ensure displacement guides entry and exit spans are perpendicular to the guide's pivot plane. Ensure steering guides have long entry spans relative to web width, an exit span perpendicular to the roller pivot plane, and a pre-entry span shorter than the entry span. **Sensing Delay Time** – Web guide sensor is too far downstream. Solution: Ensure the web guide sensor is as close as possible to the web guide exit. **Conflicting Guides** – Upstream web guide has a different lateral guide point than downstream web guide. Solution: Ensure all automatic web guide in a process are set to the same lateral position relative to machine centerline.

TD SLIP OR SHIFTING OF LAYERS IN WINDING OR UNWINDING ROLLS

Definition. Layers within a wound or winding roll slide laterally relative to each other or the core.

How to Measure. For gross sidewall errors, simply measure the variation in position of layers to a straight edge. For small sidewall errors, use a dial indicator or profilometer to measure layer position relative to a straight reference. Unwind a roll without web guiding and measure the edge position with an edge sensor. With an automatically guided unwind, monitor the guide's actuator position as an indicator of unwinding roll lateral errors.

Problems

- ✓ Scratching, abrasion
- ✓ Roll sidewall alignment is out of specification
- ✓ Laterally shifted layers are easily damage in roll handling

Mechanisms And Root Causes	1. Web shifts prior to contact with winding roll. (See the previous three sections.) 2. Layers shift within the winding roll ▪ air lubrication telescoping ▪ cinching-related telescoping ▪ deflection related telescoping (usually only slit rolls) 3. Core shifts relative to roll during winding. 4. PSA telescoping 5. Layers shift in roll handling or storage. 6. Layers shift within the roll during unwinding.

Solutions To Layers Shift Within The Winding Roll: Air Lubrication Telescoping	The outer layers of a winding roll will be fully lubricated when the entrained air exceeds combined roughness of the two web surfaces coming together at winding. Air lubrication at winding is a common problem of non-porous webs (paper, films, foils, poly-coated paper). Similar to air lubrication on a roller, a winding roll is fully lubricated when the entrained air thickness exceeds the web-to-roller combined roughness. Many products are prone to air lubrication problems if not managed properly. In winding, products are rarely modified to have increased roughness or air channeling grooves. Entrained air layers will also tend to be thicker at winding since diameters may be many times higher than roller diameter and tensions may have to be set low, tapering with increasing diameter to avoid tight roll or high torque defects. To make winding roll lubrication more complicated, the lubricated surface isn't just the short distance of a roller wrap, but potentially, many revolutions of the roller's outer layers. These outer layers are vulnerable to lateral shifting until either enough air bleeds out the sides of the roll or the pressure increase of multiple layers compresses the trapped air layer. The solutions to prevent winding lubrication includes many of the same options to prevent web-to-roller lubrication. **Solutions:** 1. Reduce the air layer thickness by limiting roll diameter, reducing speed, and keeping tension high. 2. Winding in a vacuum chamber eliminates the problem (but usually raises other problems as the benefits of air on winding friction and roll cylindricity are lost). 3. If possible in product design, consider a pattern or texture on one side of the web to manage air. 4. The most common air management solution is to winding with a roller nipping against the outside of the roll. The winding nip, found in all surface winding and many center winders, has two air management benefits. First, the nip load rejects, but does not eliminate, the amount of air that enters the winding roll. Second, under the footprint of the nip, the entrained air is compressed, creating at least a once per revolution traction point, enough to greatly reduce lateral shifting (a.k.a. air lubrication telescoping). 5. Physically restrain the web from shifting laterally with flanges, spool walls, or rotating elements. (This is certainly a bandage for the problem, but bandages are quite helpful.)
Solutions To Layers Shift Within The Winding Roll: Cinching-Related	As the name implies, cinching drives this defect, where the torque applied to the roll exceeds the roll's torque capacity. A roll's torque transmission capacity is calculated throughout a roll by multiplying any layer's internal radial pressure by its area of contact and side A-to-B coefficient of friction. More on the root cause of cinching if covered in the earlier section on MD slip in rolls

Telescoping	due to cinching. The motive for lateral motion from cinching is less obvious. For uniform gauge profile and winding conditions, there is little cause for lateral motion, but for asymmetric thickness profiles or winding conditions (such as a uneven nip load) the roll has TD variations in internal stresses that would be relieve or move to a lower energy state with the lateral shifting of roll layers. However, without cinching slip, these lateral forces are restrained by internal roll friction. Once cinching begins, the friction available in the slipping layers is consumed in the machine direction, leaving no friction available to oppose the asymmetric stresses within a roll. At this point, the layer move laterally much like squeezing toothpaste out a tube, moving away from the high stress and pressure side of the roll. Cinching induced telescoping during winding will create two zones of shifted layers. The first zone, usually near the core, will be the lateral motion of the cinching layers. The second zone, will be a misalignment of layers in the outer portion of the roll. As the inner layers slip laterally, but the incoming web continues to join the roll at the intended lateral position, the outer layers of the winding roll will build in a shifting pattern, much like when the core slips laterally during winding. **Solutions:** 1. Increase the winding roll’s torque capacity: increase tension, especially near the core, increase friction coefficient, reduce roll buildup with either larger cores or smaller final diameter, and increase crossweb thickness variations (including induced thickness variations from printing, coating, or knurling). 2. Decrease the applied torque by reducing final diameter, final tension, and accel/decel rates. 3. Physically restrain the web from shifting laterally with flanges, spool walls, or rotating elements.
Solutions To Layers Shift Within The Winding Roll: Deflection Of Slit Roll Winding Shafts	Much of winding is based on 3-in inner diameter cores; however, as the load (the vector sum of roll weight, nip load, and web tension) on the shaft increases, so too will the shaft deflection. This may not cause a problem in the center of a symmetrically deflection shaft since this portion of the shaft will still be parallel to the other rollers. However, the angles at the ends of the shaft will create an angle that will cause the web to walk laterally or create enough side load to cause the winding roll to collapse like a leaning tower. Short, small diameter rolls will usually be no problem since they don’t create high loads on the shaft. Wide rolls are also often no problem since the tensioned layers add to the bending stiffness of the shaft. The greatest shaft deflection problem occurs with winding several narrow, larger diameter rolls, especially of high density webs, such as uncoated films and foils. **Solutions:** 1. Use a cam arm to support the shaft near its center.

	2. Nip the slitting shaft from the bottom to offset the gravity load. 3. Avoid excessive nip loads. 4. Extend the shafts and provide additional rigid supports or counter bending from the shaft ends. 5. Cut the input jumbo in half and slit half the number of slit rolls per cut. 6. Use a core-dependent differential shaft since they usually have higher bending stiffness than core-lock differential shafts of the same diameter. 7. Wind on a large inner diameter core using a larger diameter winding shaft.
Solutions To Core Shifts Laterally Cases	1. **Chuck Support:** The core is relatively unlikely to slip laterally, since most chucks have collars that butt up against the core's side. However, in central drum and surface winders where the core moves away from the fixed roller as the roll builds, if the support arms are misaligned, they will shift the core laterally changing the lateral registration of the core to the outside of the winding roll. 2. **Single-Roll Shaft Support:** For wide web winding, the most common cause is the failure to inflate shaft in manual pressurizing systems. When properly pressurized or engaged, cores slip in the machine direction when the applied torque exceeds the frictional torque limit between the core and shaft. Machine direction slippage is almost always accompanied by laterally slippage. Core slip is a common problem for plastic and metal cores running on shafts designed to bite into paper cores (use of rubber elements can help). Core slip is more likely at higher applied torque from increasing tension or roll diameter. 3. **Differential Winding Shafts:** Differential shafts must slide in the machine direction relative to the winding shaft to properly function, but the challenge is how to hold the core laterally while allowing it to slip in the machine direction. Side-loading differential shafts attempt to solve this problem by physically stacking cores and spacers to hold the cores laterally. Radially-loading differential shafts usually don't include stacks of cores and spacers, so they need some positive mechanism to hold the core laterally and how a specific differential shaft accomplishes this is often one of the key features in their design. Lateral restraints include pins and bearing to physically contact the core flanks, ball bearings that indent groove the inside of a paper core, or have laterally stacked core-grabbing elements. 4. **Shaftless, Chuckless Systems:** In two-drum surface slitter-rewinders, some systems have no physical restraint to hold the lateral core position. As the roll builds, the core is free to move laterally if the roll shape is uneven. The two dominant core shifting mechanisms are: 1) a roll building into a cone-shape due to asymmetrical crossweb thickness, 2) width recovery of low modulus webs expanding laterally as winding pressure drive layers within the

	roll towards the core, dropping their circumferential tension and recovering their untensioned width. In a single roll, this would form a pear shaped roll profile, but in tightly spaced slit rolls with unconstrained cores, the width recovery pushes the cores outward, progressively worse from the center to the edge cuts.
Solutions To Layers Shift In Roll Handling Or Storage	**Cause:** Opposing forces applied to the roll exceeds friction with roll. Viscoelastic adhesive layers creep laterally in response to asymmetrical high pressures within a roll. **Solutions:** 1. Increase internal friction by increasing internal roll pressures, area, or web side-to-side coefficient of friction. Internal roll pressures increase with stiffer cores, higher winding tension, less tension taper, higher nip load, lower speed (less entrained air), lower product tensile modulus, and stiffer stack modulus. 3. Apply loads where rolls have more friction (e.g. push or pull a roll from the core or layers near the core). 4. Avoid lateral loads (e.g. unload a roll in the machine direction, rather than laterally). 5. For adhesive telescoping: Reduce roll pressure by methods listed in #1 above. Reduce viscosity and thickness of adhesive material properties. Reduce viscosity by storing rolls at reduce temperatures. Oppose lateral creep with loaded side shield or packaging. Reduce lateral motion with thickness symmetry.
Solutions To Layers Shift Within The Roll During Unwinding	Cinching usually drives this defect, where the torque applied to the roll exceeds the roll's torque capacity. The first rule of unwinding is to unwind at a tension lower than the roll was wound at, typically the final winding tension. The true goal of this rule is to avoid applying a torque at unwinding higher than was applied at winding to avoid cinching and cinching-related telescoping. Since the relationship of tension to pressure is non-linear, a roll with flat thickness profile will have less torque capacity than a roll with gauge variations. Keeping unwinding torque below a roll's winding torque does not guarantee you won't exceed an unwinding roll's torque capacity and induce cinching-related telescoping since a roll's torque capacity may change during extended storage. Torque transmission capacity is directly proportional to the internal pressure in a roll. In storage, the escape of wound in air, the viscoelastic flow of webs or coatings, the inelastic yielding of surface roughness, and many other factors may drop the pressure within a stored roll over time, dropping its torque capacity and increasing the likelihood of cinching and telescoping at unwinding. Thick, low friction webs are the most prone to unwind telescoping.

	Besides cinching-related telescoping, lateral shifting may be induced by hyperactive sidelay web guiding or uneven stresses associated with a deformed slit edge or asymmetrical thickness profile. **Solutions:** 1. Increase an unwinding roll’s torque capacity at winding: high tension, especially near the core, high friction coefficient, less roll buildup by either larger cores or smaller final diameter, and increase crossweb thickness variations (including induced thickness variations from printing, coating, or knurling). 2. Decrease loss of torque capacity in storage by reducing air entrainment, changing material properties or storage conditions (such as refrigeration) to reduce viscoelastic flow or shrinkage, and reduce storage time. 3. Reduce lateral or asymmetrical forces on the roll from sidelay guiding, slit edge quality, and gauge profile. 4. Physically restrain the web from shifting laterally with flanges, spool walls, or rotating elements.

SUMMARY

Maintaining control of a web in both the machine and traverse directions on rollers and in winding rolls are two of the primary responsibilities of web handling. This guideline to understanding their root causes and targeted solutions should provide a useful checklist to solving the most common forms of these problems. This guide was designed to be a thorough review of the topic, but is also an invitation to others for additions or corrections to make it a more complete resource.

REFERENCES

1. Walker, T., “Practical Application of Idler Roller Performance Measurements and Models,” Proceedings of the Twelfth International Conference on Web Handling, 2003. WHRC, Oklahoma State University.