# READING A ROLL

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## ABSTRACT

Web or winder defects often leave a visible record of themselves in the wound roll that can be read much like the rings of a tree. Varying strains in each layer as it is wound will cause changes in geometry that can be observed visually or with simple tools. These cylindricity deviations are a fingerprint of the cause of the defect.

This paper shows how to read a roll's history by diametral variations across its width, by radial variances around the periphery, and by variations in width or CD position. Additionally, the winding mechanics that produced the cylindricity deviations will be discussed. Defects covered include corrugations, dishing, ridges, starring, telescoping, and many others.

## THE WOUND ROLL AS A RECORD

Wound rolls record a history of the raw materials they were made of and the machine they were made upon. If we know how to read the record we can troubleshoot the web and winding process. Reading a roll is not unlike reading the seasons from annular growth rings on a tree, or the success of a species from fossils frozen in a sedimentary strata, or the habits of a people from an archeological dig of an ancient city. Any of us can read the history if we have sufficient sensitivity and training.

While archaeologists, paleontologists and winder technologists all have specialized tools, visual inspection still remains most important. It is fortunate that most roll defects are visible so that special instrumentation is not needed.[1] Indeed, visual inspection can usually resolve defects better than most roll structure measurements[2] and also outperforms most process sensors and lab test measurements.[3] Thus, measurements support rather than supplant visual inspection. Researchers are working to replace the operator's inspection and disposition of wound roll condition with less subjective mathematical modeling or measurement techniques. However, manual inspection still remains the fastest and surest means to detect most wound roll troubles.

Some wound roll defects are so obvious that they can be seen at a glance from across the room. Vivid defects include telescoping, and starring. Other wound roll defects are so subtle that one must look quite closely. Subtle defects include crepe wrinkle and slitter edge cracks which may need a magnifying glass to be seen clearly. Some defects can be more easily resolved using simple tools such as straight edges and tape measures.

When troubleshooting winding troubles, is important to know that defects form at different parts of the wound roll's life cycle. Crepe wrinkles and bursts, for example, form within seconds of winding. Flat spots and other out-of-round troubles happen during the first minute of handling and storage. Finally, blocking, core bursts and telescoping are created or become apparent only upon unwinding. Thus, a single inspection may not always pick up an incipient defect. A roll must look good before, during and after winding before it can be declared trouble free.

## ROLL SHAPE MEASUREMENT

Many wound roll defects are a deviation from a perfect cylinder, or more precisely, coil. We could classify these geometrical deviations as variations in diameter, periphery (out-of-round), or width (roll edge condition) as seen in Figure 1. While some roll defects can be readily seen without aid, others will be better resolved with simple tools or instruments. Also, measurements are necessary to quantify roll deviations for serious quality control and troubleshooting efforts.

Variations of diameter across the width, dr(z), can be measured in a number of ways. The simplest is to place a straight edge along the top of the roll so that caliper ridges and valleys will stand out better. However, this is nonquantitative and will not detect the conical portion of roll cylindricity error. A better approach is to measure a mean diameter using a flat tape about the roll's circumference. While this is accurate, it can be time consuming and unwieldy. The roll may need to be upended or suspended by the core so that the tape can be fitted around the outside. While there are other instruments for profiling diameter across the width, they appear cumbersome.[4]

Deviations across the width can also be inferred from some of the roll structure measurements because large diameter portions of the wound roll tend to be harder or tighter. Measurements which profile across the width include all of the impact hardness devices such as the Backtender's friend,[5] billy club, Paro Roll Tester, Rhometer[6,7] and Schmidt Hammer.[8] Additionally, interlayer pressure transducers, the Cameron gap test[9] and other means might also profile tightness across the width. Unfortunately, small ridges and valleys are often too closely spaced for many of the roll hardness instruments. Fine features are often better seen by tracing the outside of the roll with a flat crayon pad.

Variations in periphery, dr(θ), due to out-of-roundness are less commonly measured. A simple means of measure is to use a flat tape from the ID of the core to the OD of the roll at various radials. A better documented approach is to make a polar graph of the radial runout with the Radiavarius chucked into the cores [10]. A more involved means is to turn a wound roll in concentric chucks and measure TIR (total indicated runout) with a dial indicator. In addition to measurement difficulties, the periphery tends to change shape more than diameter or width because it can be easily distorted during any handling or storage process step.

Variations in width or axial position are easy to see but are very hard to measure. For example, a single layer offset the thickness of a human hair and jutting out only a millimeter can be easily seen against an otherwise straight roll edge. However, it would be difficult to mechanically measure that stickout without deforming it. The simplest way to measure gentle changes in roll edge shape, such as dishing or width expansion, is by ruler between the roll edge and a straight edge. An indirect but automated means of measuring variations in axial position is to use an edge sensor just upstream of the roll during winding or unwinding.

## DIAMETRAL VARIATIONS

Figure 2 shows diameteral variations which include the ridge and the valley. While ridges are most often areas of relatively high caliper, they can also be longer or baggy. In the first case, the roll is larger there because it contains more material, while in the second case it is larger because it contains more material and it is looser. If a ridge is within a few millimeters of a valley, a corrugation (a.k.a. rope or chain mark) may form. Beware, however, that the size of the caliper variation which can generate a corrugation might be too small to measure with online or lab tests. Also, the spacing of the caliper variation may be too close to be resolved by typical measurement methods or controlled by typical profile actuators.

What is interesting here is that the wound roll is far more sensitive to caliper than most online or lab instrumentation. Thus, just because a caliper gauge can't detect a ridge or valley doesn't mean that its not there or that it doesn't affect the wound roll. For example, we can easily measure a diameter or circumference difference of 1 part in 1000. Conversely, caliper measurements have difficulty resolving even 1 part in 100, or sometimes even 1 part in 10 on very thin materials. Note, however, that caliper errors do not stack up proportionately because thick spots which would cause larger diameter are also wound tighter which tends to moderate the diametral variation. Thus, while relatively incompressible materials may stack to diameters nearly indicated by their caliper, wound rolls of spongy materials may show diametral variations across the width more due to MD tension variations than due to caliper variations.

Figure 3 shows raised edges due to slitting, which is a common difficulty with film slitting regardless of the method used. What differentiates this from a caliper ridge caused by the maker is that it occurs wherever a slitter is dropped into the web. Sometimes the web, roll or slitters must be oscillated to prevent this defect from growing unstably on light film. Similar diameter variations can be caused by other converting processes such as coating, glueing, printing, folding and so on.

Finally, Figure 4 shows a cone shaped roll. It is possible that this shape resulted from a linearly varying caliper from the maker. However, the winder is also capable of producing this shape from uniform material. If a nip roller is not parallel to the wound roll's axis, the nip pressure will vary from one side of the machine to the other. This will cause the roll to be built small on the high pressure close side and large on the low pressure open side.

Caliper variations may be far more detrimental in winding than in end use. In other words, the base sheet itself may not be compromised by caliper variations that result in rejected wound rolls. Winding difficulties include excessive local nip pressures, bagginess, wrinkles and sheet steering. First, areas of relatively high caliper take a disproportionately large share of the nip pressure, which may damage some delicate materials. Second, diametral variations can cause an uneven stretching of the web around the roll so that bagginess might result. Third, a web tends to move to the high diameters of roll(ers) in traction. Thus, a thin web may gather on a tiny bulge which feeds on itself unstably. Fourth, a diametral variation causes the web to steer toward the larger side.

## PROBLEMS ON THE PERIPHERY

Out-of-round rolls can cause difficulties with the supplier as well as their customers as the rolls may not wind or unwind smoothly. If the winder/unwind is purely center, the web run will bounce with tension oscillations. If the winder/unwind has a nip, wound roll vibration will result, which is an exceptionally difficult problem to solve.[11,12] In either case, excessive roll runout may require slowing down the machine to avoid web damage or even web breaks.

Rolls may become out-of-round during the winding process, and will thus cause troublesome or even dangerous levels of vibration. While this can be the result of a winding machine design or operation deficiency, it is often the result of an instability of the web material itself. Grades which are prone to this type of vibration often include those which are bulky and/or have high web-web friction coefficients. Examples of these grades include book, carbonless, tissue and sometimes others such as LWC or news. As seen in Figure 5, bouncing grades will deform and retain the deformation of any disturbance of the nip. This deformation provides a bump for the next revolution, and so the problem builds. The roll runout which causes noticeable vibration may be not much more than a hairsbreadth in amplitude when winding stiff materials at high speeds. In more severe cases, rolls of softer materials with eccentricities more than one inch can be wound and unwound, albeit at slow speed.

More often, however, a wound roll becomes deformed during storage and handling. Some storage means, such as the belly sling or slowly rotating the roll during core support, provide the greatest resistance to distortion. Setting the roll on the floor is the worst. Some handling methods, such as the clamp truck, are notorious for leaving a pair of flat spots[13], which has led to minimal clamp force designs.[14,15] While the prong truck can be less damaging, it is weight and width limited. Finally, conveyor stops and kickers can leave a dent in the roll. Figure 6 gives a few of the more common roll distortion mechanisms.

In most cases, it is easy to diagnose the cause of the problem because the shape of the deformation is a fingerprint of the machine component that made it, for which solutions will suggest themselves. For example, clamp pressures can be reduced or intelligent clamps can be employed. If a roll stop is the culprit, the rolling velocity can be decreased or the stroke of the stop increased. Note that one should work with reducing the force far more aggressively than by reducing the time of force application. In these problems, the residual distortion is approximately a function of log time. Thus, for example, setting a roll down for a hour may distort it only little more than setting it down for a moment

Another approach to keeping rolls round is to wind them as tight as the web, roll or machine will allow. This is because winding tightness causes interlayer pressure which increases the friction between layers. Friction is important because it is the 'glue' which hold the roll together. It is not unusual to see a reduction of handling distortion as much as a half when changing tightness from the minimum to the maximum of a practical range.

## ROLL EDGE TROUBLESHOOTING

Desirably, a wound roll should have edges that look like they were cut by a laser. A high quality edge means that it is flat and smooth. However, the physics of the wound roll will cause width to swell as seen in Figure 7. Here, radial (interlayer) and tangential (MD) compressions cause a smoothly varying width increase due to the Poisson response. The roll is narrowest at the top because the interlayer pressure is lowest and the MD tension highest and vice versa deep in the roll.

In most materials, the width changes are very small and present no difficulty. However, this width change can be profound and permanent on materials such as nonwovens. Here, the material remembers something of its position varying width it was forced into in the wound roll. Also, the width increase can cause interior rolls to push the centers of outer rolls outward into a dished or telescoped shape. This problem which is compounded on wide machines cutting numerous rolls will be characterized by symmetrical and progressively increasing outward dishing for rolls further from the center of the machine. The only way to reduce the width increase is to change the material's properties or wind looser. (Symmetrical and progressive outward dishing can also result from causes other than width growth, however.)

Superposed onto the nominal roll shape are subtle edge variations that result if the slit width, winding tension or web path varies. These edge disturbances can be read much like the growth rings of a tree. Figure 8 shows a troubleshooting diagram which first separates an edge disturbance into a width variation and/or a offset. Though the wide and offset wrap may look similar on one side, there is almost nothing in common with their causes. The easiest way to separate the type of edge disturbance is to peel the roll down to the layer in question. A layer with two 'outsies' is wide where an outsie on one side and an insie on the other is obviously an offset wrap. This basic diagnostic technique can be adapted to suit most any winding situation. This technique may also be used for the troubleshooting of registration problems.

The width change may be caused by variations of web tension through the slitter section. Width changes can also result if the slitter blade is allowed to move. For example, a bottom slitter band that is allowed to wobble will cause the edge to be cut into a scallop with a wavelength nearly equal to the circumference of the band. This scalloped slit edge will wind up into an interference patterns on the edge of the roll. These patterns yield a bullseye appearance with 'slitter ring' diameters corresponding to integral numbers of bottom blade diameter.[16] Finally, any web sag, flutter, wrinkle or other out-of-plane feature through the slitter section will result in a wider cut width.

Roll width variations will also result whenever the WIT (Wound-In-Tension) of the roll changes due to variations in the TNT's (Tension, Nip and Torque) of the roll. For example, if the web tension is momentarily tighter as it enters the windup, it will be narrower on those layers due to Poisson contraction. Another example is the stick-slick phenomenon of excessive nip control system friction that can cause a sawtooth appearance of the roll as seen in Figure 9. Also, changing speeds on a surface winder will cause inertial tension upsets as few if any winders compensate for this effect. Finally, machine vibration will cause the roll edge to take on a fuzzy or sometimes corrugated appearance.

An offset wrap will result if either the web or roll moves sideways during winding. To improve the tracking of the web, the web and machine should be quite uniform. Also important is to shorten the spans between the winder and the maker or slitter as much as possible to give the web less chance to wander sideways.

However, the roll can also move sideways in a variety of ways. Perhaps the most common is due to poor maintenance of the winding machine which allows axial play in the shaft or core system. Other causes include axial thrust loading on surface winders which can swage the ends of cores up onto the corechucks and even deform the winder frame. This axial thrust can be in either direction and can be as large as the friction coefficient times the nip load.

Finally, interlayer slippage inside the roll during winding or unwinding can allow both MD and sideways movement. Interlayer slippage is best detected by the J-line drawn on the side of the roll.[17,18] Here, an initially straight line will bend into an arc as layers shift under the rolling nip as seen in Figure 10. Note that the rolling nip can be internal due to core support as well as external as in surface winding. Note that the direction of movement is different for winding and unwinding as well as for bulky and stiff materials. While the details of this interlayer slippage under a rolling internal or external nip are quite complex, the effects are quite well known. This interlayer slippage is responsible for many winding defects including the burst, core burst, corrugation, crepe wrinkle, telescope and more.[19]

For example, the telescope occurs where the layers broke free first in the MD, which then allows a possible sideways shift. While the tension induced torque could be a factor in the MD slippage, the more common factor is the rolling internal nip of the weight of the core supported roll. We can let the winding roll teach us how to program the tension curves to avoid telescoping of the core supported roll. As seen in Figure 11, the winding tension is begun at the highest value the web or machine can sustain. The tension level is maintained until the roll begins to J-line down near the core. When the J-line shifts, the winding tension is dropped until it freezes again and so on in a stepwise fashion.

Finally, one makes a program which clears the undersides of the steps. Note that the maximum roll diameter that any particular grade can be wound to is the intersection of this winding tension curve with the minimum tension the grade or winder can sustain. Also note that the resulting ideal tension program to avoid the telescope is far different than the constant tension, taper tension or constant torque curve in common use.

Dishing during winding can also happen if the cores are allowed to move during winding. This may happen due to slippage on a core shaft or axial play in the shaft or chuck system. If the winding arms or ways are misaligned, the rolls will build into cones. Finally, dishing can happen due to the roll growth or Poisson effect discussed earlier which yields a progressive outward dish. Figure 12 summarizes a few of the types of dishing during winding.

Figure 13 shows some of the other common roll edge conditions you may run across. To get a proper start, the cores must be aligned to where each of the lanes will track after slitting. If a lane is forced off of its desired path when taped to the roll, it will return there by time a dozen or so web widths have been run after start. Also, the operators must make sure the lanes are evenly taut through the machine and squared with the core before taping. A problem here is not pulling enough web through on threadup.

Sometimes the roll edge will show an edge disturbance corresponding to the top and bottom of speed changes. This disturbance could be wide, narrow, offset or a combination. While this disturbance is commonly known as an acceleration offset, it is really a drive system problem where tensions are not being held properly during the challenging dynamics of speed changes. As seen in Figure 14, a web that changes its state of traction (due to a tension upset) will change its path through a machine at a misaligned roller.

Finally, starring or spoking as seen in Figure 15 indicates poor roll structure and/or abusive handling of the rolls. In almost all cases, starring can be avoided by making sure that the foundation of the wind is solid (no core crush) and continuous (no core keyways for example) and that the roll is properly roll structured (tight start, looser finish, bumpless curve).

## SUMMARY

We need not wonder overmuch whether our rolls are well wound and free of defect. If they look good upon close inspection, they probably are. All we need for tools are our own eyes, perhaps supplemented with a tape measure, straightedge and pencil. Granted, modeling and measurement have and will continue to provide insight and understanding. However, these techniques have not been widely employed as they are more complex and not as discriminating as simple visual inspection.

Most defects are readily visible from the exterior. Only a few such as blocking, bursts and some wrinkles tend to be hidden from view in the interior of the roll, and thus must be detected upon unwinding. Rarely do defects require instrumentation to detect, such as caliper loss due to interlayer pressure.

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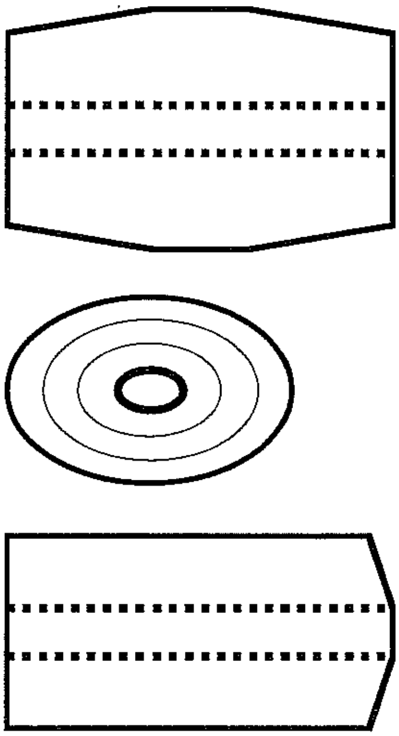
**Figure 1 - Roll Shape Variation Examples**



**Diametral Variation**

**dr(z)**

**Peripheral Variation**

**dr(θ)**

**Width & Position Variation**

**dz(r)**

**Figure 2 - Caliper Ridge and Valley**

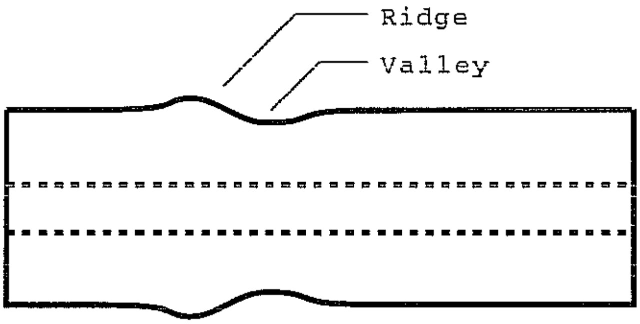


Figure 3 - Raised Edges Due to Slitting

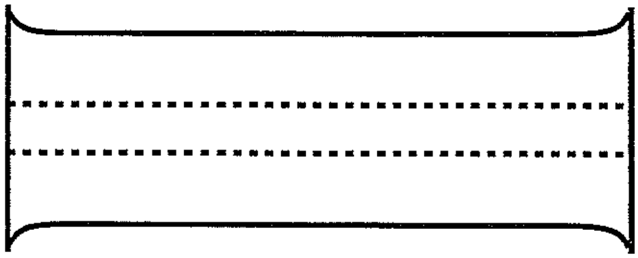


Figure 4 - A Cone Shaped Roll

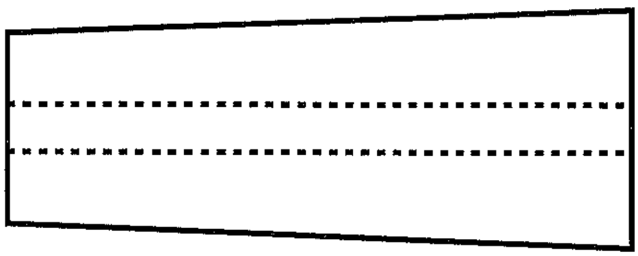


Figure 5 - Washboard Road Analogy for Roll Vibration

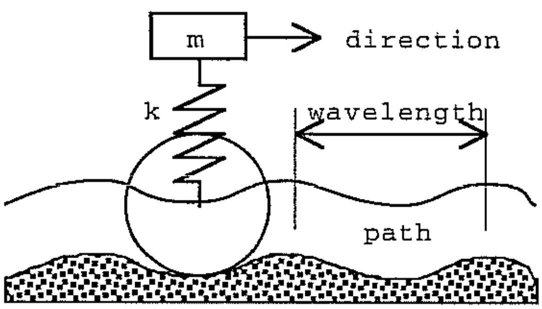


**Figure 6 - Some Roll Deformation Causes**

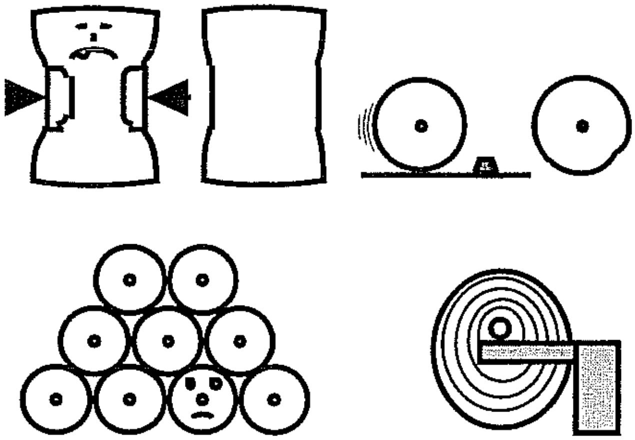


**Figure 7 - Roll Width Growth Due to Poisson Expansion**

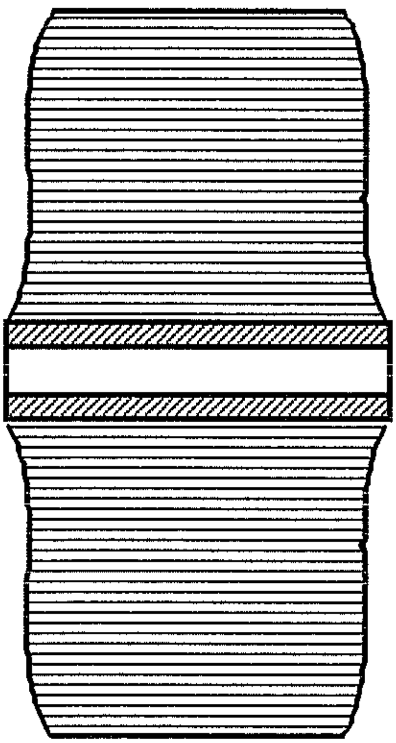


Figure 8 - Roll Edge Disturbance Troubleshooting

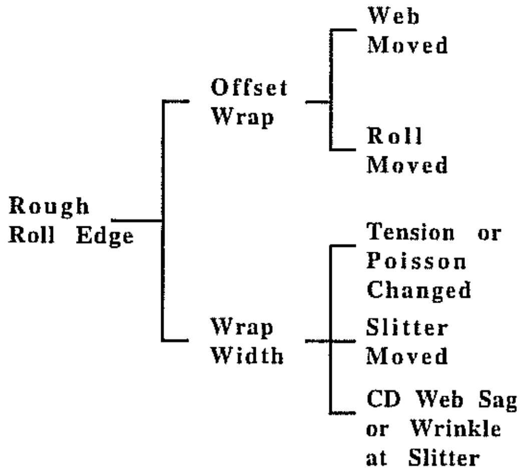



Figure 9 - Sawtooth Edges Due to Nip Friction

**Figure 10 - J-Line Slippage Cases for Bulky Materials**

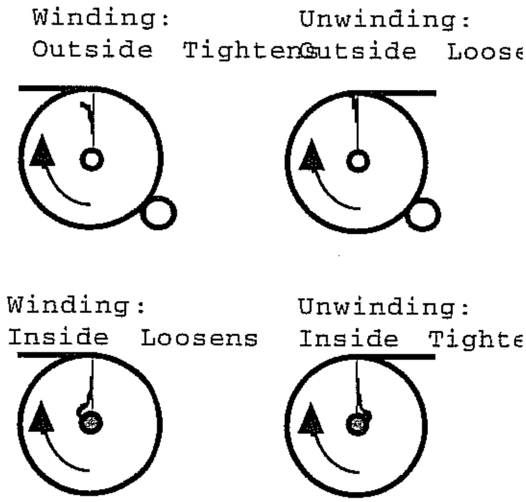



**Figure 11 - Tension Program to Minimize Telescoping (on a pure centerwinder)**

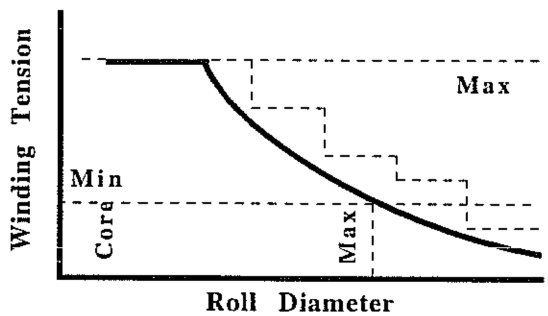


Figure 12 - Dishing Examples

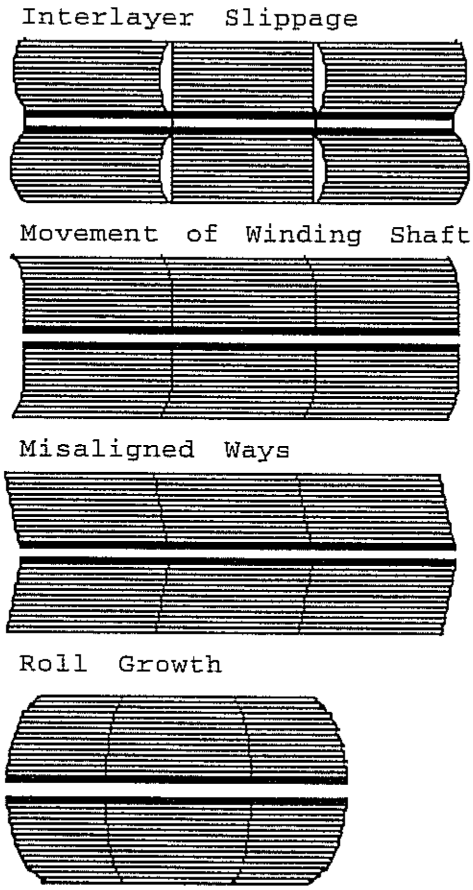


Figure 13 - Edge Disturbances Near the Core

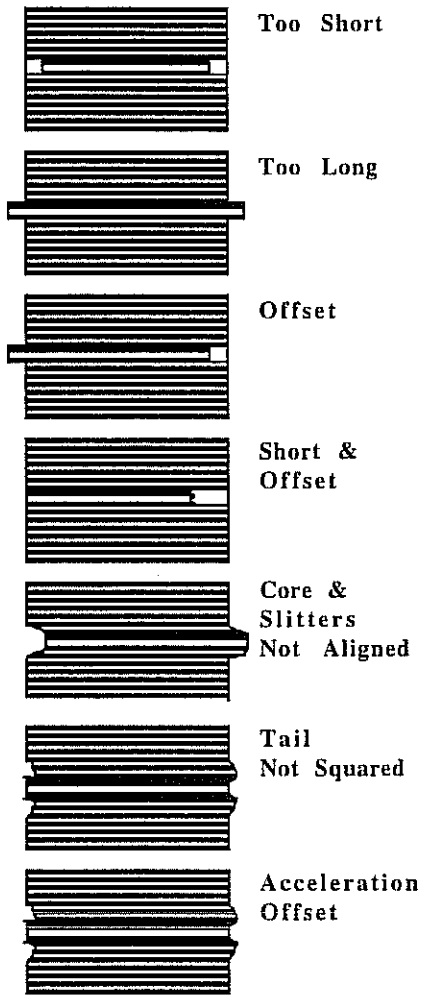


**Figure 14 - Offsets Due to Changes in Traction**

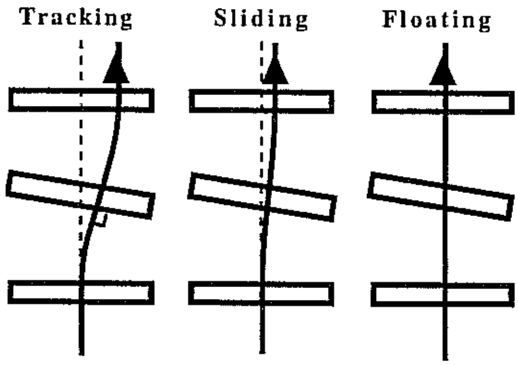
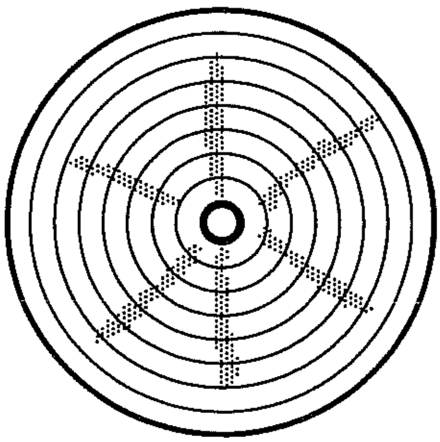



**Figure 15 - Starring**



Question - David, is there any evidence that shipping good shaped rolls to press room has improved runability; but the break-rate hasn't decreased in many many years?

Answer - Undoubtedly if you bang the roll up too much you get tension surges that will increase probabilities of breaks, but by and large most of the web breaks are not caused by these tension surges, otherwise we would not have a grouping of breaks at the outside - 2 minute breaks, for example, and breaks at the core. Shipping a roll round is a good idea, but doesn't solve all of our problems. We are addressing other issues today.

Question - The three methods really are a triad and that is how they should be used. If you really emphasize the observational leg how do you propose we optimize processes and conditions for products that don't exist yet? And how are we to assure that the products we do have are operated in the most robust fashion if all that we can really look at is problems when they occur?

Answer - That was a very good question, but I was not proposing that we don't measure and that we don't model and for heavens sake I was not proposing that we stop research. All this was my sincere evaluation of the state of the art of the winding science as brought to the plant right now. You guys are going to need to do something else about this.

Question - How much is the inability to produce perfect coils just a matter of economics rather than a lack of understanding of the technology?

Answer - Let me rephrase this: How much is web handling winding waste costing us? Typically several percent in every mill in the plant.

Question - If we understand the technology and the variables when controlling the variable then we should expect perfect coils.

Answer - Absolutely not, because winding is not deterministic. The things that make winding interesting is why this roll has problems and not the next. Many times it is the variability that we haven't even attempted to work with yet that describes the things of interest. Most of the times we wind without defect. Otherwise we wouldn't be in business. We are working with a couple of percent on the tail end of a variation of the nature of which we don't even understand in some cases. No, you cannot make deterministic models that will clear you of all problems when many of them are due to variations out of the means.