USING A WINDING MODEL TO REDUCE WINDING DEFECTS

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ABSTRACT

As a roll is wound, stresses in the roll develop - and change as the roll builds. The stresses on each layer in the wound roll influence whether the roll is likely to telescope, star, cinch, yield, block or ooze - to name just a handful of winding defects.

Finding the right balance between “too tight” and “too loose” defects can take significant trial time and material. Changing several winder inputs simultaneously increases the problem complexity - especially if a wide range of materials is also involved.

This paper discusses how a 1D winding model can be used to speed the troubleshooting process to optimize winder settings to avoid winding defects.

NOMENCLATURE

TD, CD	Transverse Direction or Cross Machine Direction
MD	Machine Direction or Tangential
DOE	Design of Experiments
E_r	Radial Modulus
P	Pressure for Radial Modulus Test
K_1, K_2	Pfeiffer equation constants for radial modulus
t	Thickness
E	MD or Tangential Modulus
T	Tension, Force/width
ε	Strain

INTRODUCTION

Reducing winding defects is challenging because they are often hidden in the layers of a wound roll or don’t express themselves until later – sometimes in transport to or on the unwind stand of a downstream process. Winding model outputs – stress profiles within the roll – are the link between winder parameters and winding defects. In this paper, modeling examples of pressure sensitive adhesive laminates on center winders and center surface winders are shown. Winder 6.2, a one-dimensional model developed by the Web Handling Research Center of Oklahoma State University was used [1].

WINDING DEFECT REDUCTION STRATEGIES

It is difficult to reduce winding defects by optimizing winding parameters without knowing their impact on the stresses within a wound roll, especially when trying to simultaneously avoid "too tight" and "too loose" defects [2].

Iterative tweaking of the winding knobs is a common method because it is easy. This requires waiting for the impact of the previous adjustment to manifest – sometimes as a reduction in defect complaints but sometimes as a change in defect. For example, the frequency of "too tight" defects may be reduced while the frequency of "too loose" defects now increases requiring another round of tweaking. This method is usually slow unless the downstream customer is involved in evaluating the rolls and giving feedback outside the normal complaint process.

Another strategy involves the use of DOE (Design of Experiments). Several winding parameters can be simultaneously changed in a specific way to study a particular parameter space. Depending on the number of factors to be studied, this method may require significant equipment time and material which may end up as scrap or rework. The benefit of DOE is that any interactions between factors can be seen and the process is faster than the "tweak, wait, repeat" method.

A third strategy uses a winding model in combination with DOE. The outputs of a 1D winding model are the radial and circumferential stresses in the wound roll as they change with roll radius. The output is not roll quality – but the stress profiles can be overlaid with defect maps based on correlations between roll stresses and actual defects – to enable parameter optimization. This third strategy can greatly reduce machine time and material needed.

CHALLENGES

The use of a winding model requires additional information: material property data and winding parameters in engineering units. Often on older winders or slitters, the winding tensions and nip loads are not displayed in engineering units but are shown as "% of something" or "1-10" on a knob. In this case, calibration or sometimes additional instrumentation is needed to get the right inputs to enable use of the winding model.

Using a winding model as the link between machine settings and roll defects is particularly helpful when a range of materials is run on a variety of winder types. The optimized settings of a center winder do not transfer to a center surface winder. The best settings for a paper/paper laminate won't be the best for a film/film or film/paper laminate. Multiplying hundreds of products on dozens of machines makes for a huge optimization effort.

WINDING DEFECTS

Of the many winding defects possible [3], those common for pressure sensitive adhesive (PSA) laminates are:

1. TD buckling

2. Adhesive Edge Ooze
3. Telescoping
    a. Too loose – telescoping during winding or handling
    b. Too tight – telescoping during transport or storage, aggravated by variation in CD caliper
    c. Too loose at the core – telescoping on an unwind with J-line slippage [4]

MATERIAL PROPERTY INPUTS

Two of the material property inputs for the model are MD modulus and radial modulus. Radial modulus is described by K1 and K2, Pfeiffer's constants [5].

$$E_r = K_2(P + K_1) \qquad \{1\}$$

The product of MD modulus and thickness, tE, is the proportionality constant between tension and strain and better describes the behavior of a particular web than does modulus alone [6].

$$tE = \frac{T}{\varepsilon} \qquad \{2\}$$

Figure 1 below shows how K2 and tE range for the materials modeled. Compressible webs (paper/paper) have a lower K2 than incompressible webs (film/film). Film/film laminates have lower tE than paper/paper ones and strain more under the same tension. Film/paper laminates, depending on their components cover a wide range. The impact of changing material parameters is not included here, but the data is shown as part of the motivation for using a winding model.

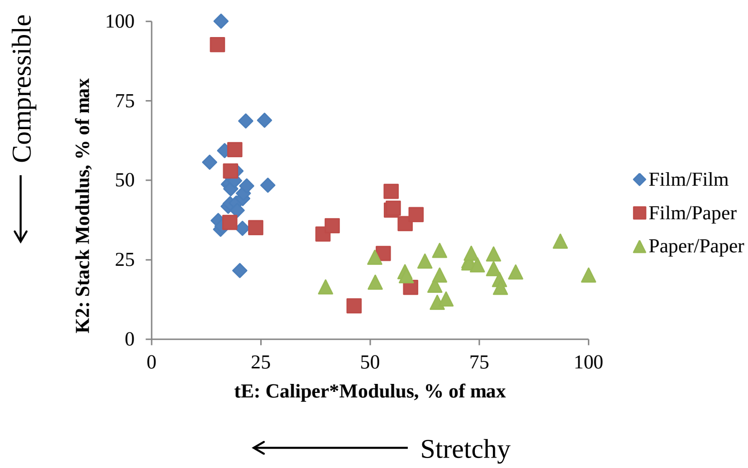

Figure 1 – MD and Radial Moduli for Film and Paper Laminates

WINDING MODEL OUTPUTS

Radial Pressure or Interlayer Pressure (Figure 2) and Circumferential Stress or Tension in the Wound Roll (Figure 3) vs Radius are the major outputs of a 1D winding model. Interlayer pressure is highest at the core and drops to zero at the outer diameter (OD). Circumferential stress (or tension in the wound roll) in the early layers dips (often into compression) as the outer layers squeeze the inner layers and it then rises to wound on tension at the OD .

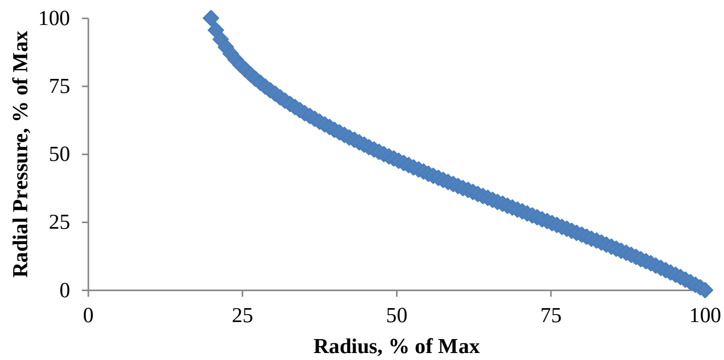

Figure 2 – Interlayer or Radial Pressure

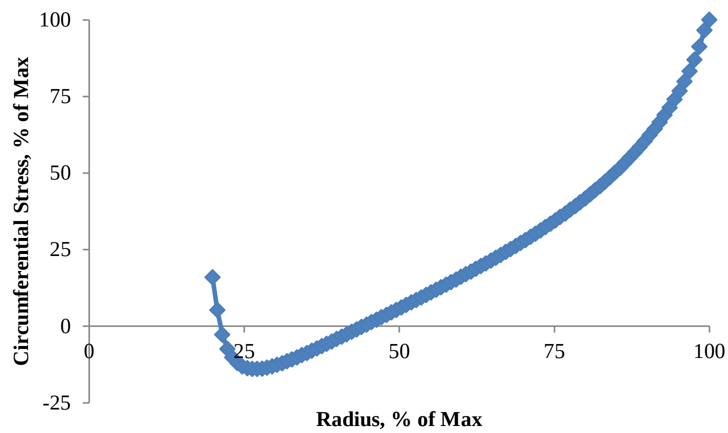

Figure 3 – Tension in the Wound Roll

A winding model links the material property and winding parameter inputs to the outputs of pressure and tension throughout the wound roll – but not to roll quality. The link between wound roll quality and the stress profiles will be called a defect map here. A more optimistic perspective would be to call them operating windows as Roisum does, but when focused on defect reduction, it seemed appropriate to call them defect maps [2].

DEFECT MAPS

The empirical defect maps are a way to tie the actual defects to the modeled stress profiles. There is a map for Pressure Defects such as telescoping, ooze, blocking and embossing, and another map for Tension Defects such as TD buckling and yielding. The pressure defects map (Figure 4) includes 3 regions of telescoping and a high pressure area where blocking, ooze and embossing are likely.

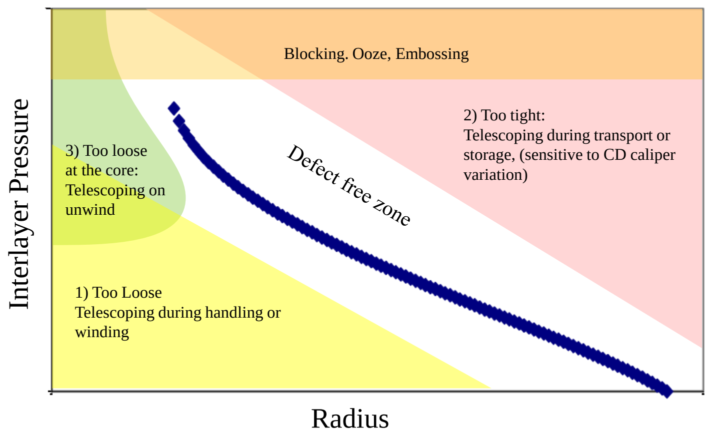

Figure 4 – Pressure Defects Map

The Tension Defects map (Figure 5) shows a region of negative tension (compression) where TD buckling is possible. It doesn't start at zero because some compression is tolerable without buckling because the layers are stabilized by the interlayer pressure.

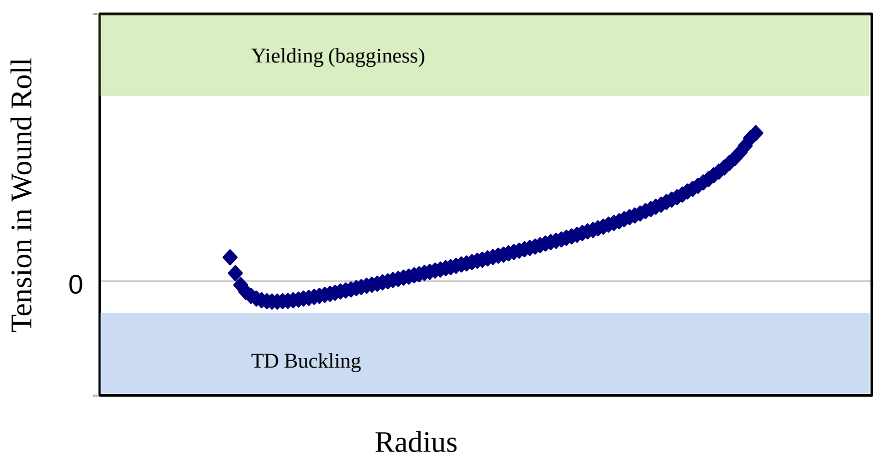

Figure 5 – Tension Defect Map

WINDER INPUTS

In the examples that follow, for a center winder with a nip, the nip load (N0) was constant and the rewind tension was tapered (T0, Tf). For the center surface winder example, the rewind tension was constant (T0) and the nip load was tapered (N0, Nf). Because the term "taper" is usually confusing, tapering is described by start and final conditions or start and final/start ratio.

Parameter	Start	Final	Taper
Nip Load	N0	Nf	Nf/N0
Rewind Tension	T0	Tf	Tf/To

Table 1 – Tension and Nip Parameters

EXAMPLES

Pressure Defects on a Center Surface Winder

In this example, a winding model was used after winding parameters had been adjusted several times. After finding that rolls were too loose, the operators increased the start and end nip. This had the effect of making the rolls too tight and having adhesive ooze to the slit edges of the rolls. The operators then reduced the end nip. The rolls were still too tight (too much ooze). A third adjustment was made, reducing the start nip. Then the rolls were defect free – neither too loose (falling apart) nor too tight (ooze). Table 1 is a summary of the runs.

Profile	Start Nip	End Nip	Condition
A	Low	Low	Loose
B	High	High	Ooze
C	High	Low	Ooze
D	Medium	Low	Good

Table 2 – Nip Profiles and Roll Condition

Figure 6 shows the nip profiles used. Figure 7 shows the interlayer pressure profiles from the model output with defect zones sketched in.

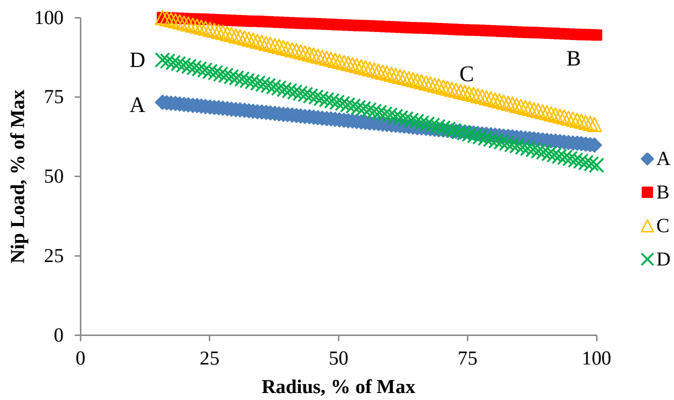

Figure 6 – Nip Load Profiles for Pressure Defects on Center Surface Winder

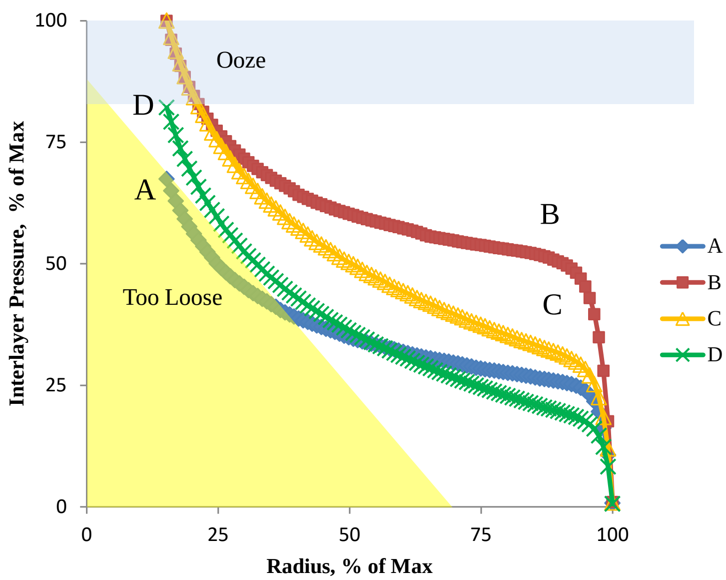

Figure 7 – Model Output with Defect Map

This issue was resolved without the use of a model – but modeling after the fact helped clarify the combined effect of start and end nip and became a good illustration of balancing "too tight" and "too loose" defects.

Tension Defect on a Center Winder with Nip

For this example, the same material was wound in two different locations but one location was experiencing TD buckling. Both locations were center winding with a nip and using a non-linear rewind tension profile (Table 3).

Profile	T0	Tf/T0	Features	Condition
B	100%	65%	Higher start, less taper	TD Buckling
A	80%	40%	Lower start, more taper	Good

Table 3 – Tension Profiles and Roll Condition

Figure 8 shows the input tension profiles and Figure 9 shows the model output for circumferential stress. For the roll with TD buckling, the circumferential stress dips much lower into compression than for the roll without buckling.

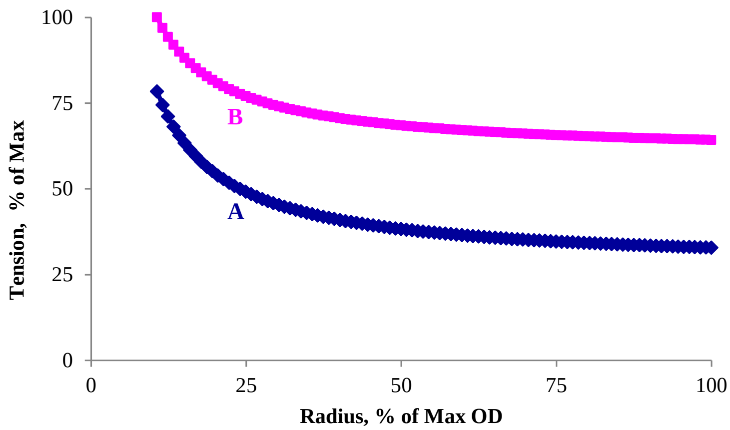

Figure 8 – Rewind Tension Profiles

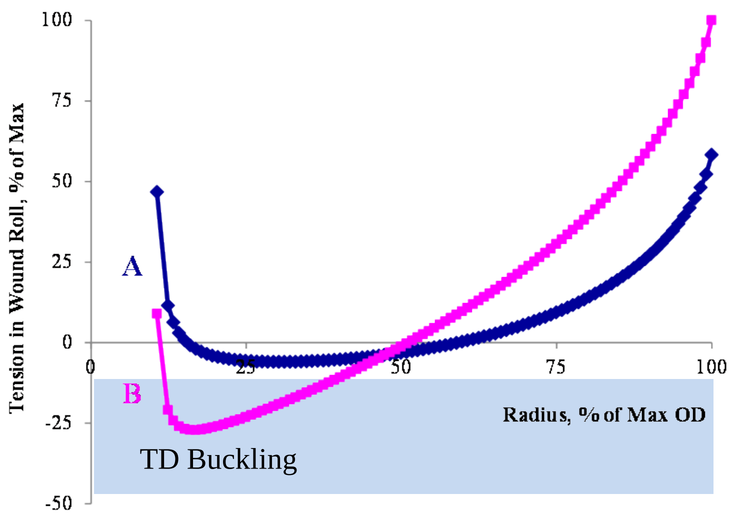

Figure 9 – TD Buckling

This example too could have been resolved without the use of a winding model by just copying the tension profile from the defect free site. But here the stress profiles clearly show the impact of rewind tension on circumferential stress which is not as intuitive as interlayer pressure is.

Pressure Defects on a Center Winder with Nip

This example also involves balancing “too tight” and “too loose” defects but uses a DOE strategy to fine tune the tension profile. Initially in response to rolls being too loose, the start tension, end tension and nip load were all changed. This resulted in the rolls being too tight and telescoping in storage. Both conditions were used as limits to explore the impact of different combinations of the factors within these limits. Table 4 and Figure 10 show the design of the DOE which is a 3-factor, 2-level design with a center point.

The idea was to model the 9 combinations of factors and levels and to use the resulting stress profiles with the original 2 defect conditions to decide which 1 or 2 combinations were to be actually run in production as confirmation trials.

Run	T0	Tf/Ti	Nip Load
1 (Loose)	Low	Low	Low
2	Low	Low	High
3	Low	High	Low
4	Low	High	High
5 (CP)	Mid	Mid	Mid
6	High	Low	Low
7	High	Low	High
8	High	High	Low
9 (Tight)	High	High	High

Table 4 – DOE factors and levels

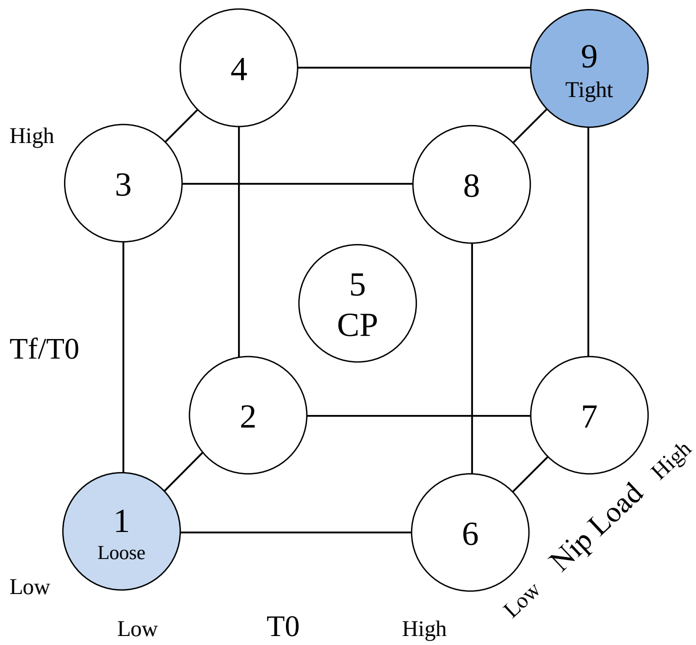

Figure 10 – DOE Runs in Table 4 for Winding Parameters

Figure 11 shows the interlayer pressure profiles for the nine runs. Nip load had a small impact over the range modeled so to simplify the graphs only one level of nip load is shown in Figure 12.

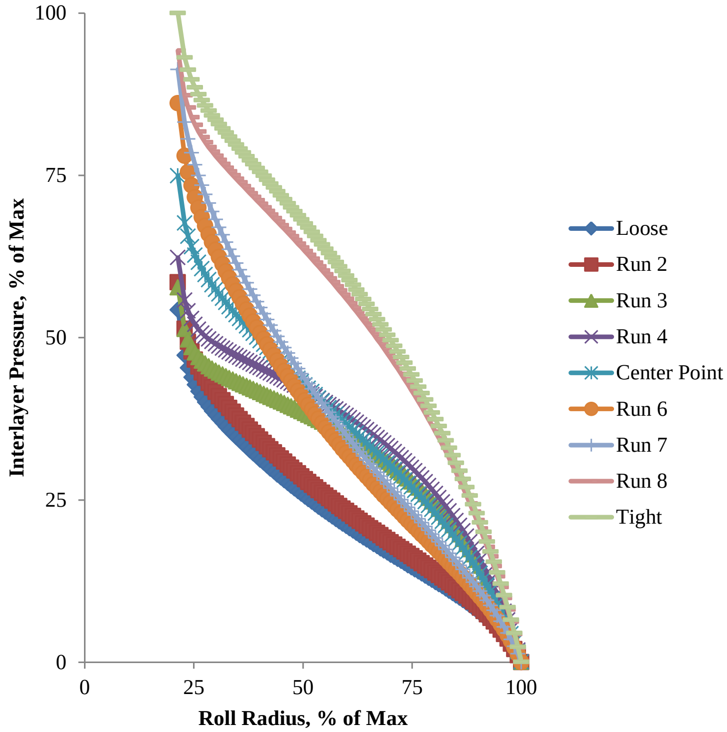

Figure 11 – Model Output from DOE Runs

Since Run 1 was loose and Run 9 was tight, Runs 4 and 7 could be run to fine tune the tension profile to avoid adhesive ooze and possibly J-line slippage (too loose at core).

Although this example focused on pressure defects, looking at the impact on parameter changes on circumferential stresses is also important so that pressure defects are not swapped for tension defects like TD buckling. Looking at Figure 13 shows that the "Tight" run had the most compression and would be the most likely to buckle, so changing the parameters to avoid too tight defects would not introduce TD buckling in this case.

Although this is a relatively simple example of combining winding modeling with DOE, there are over a dozen model inputs that could be looked at for relative impact and significance.

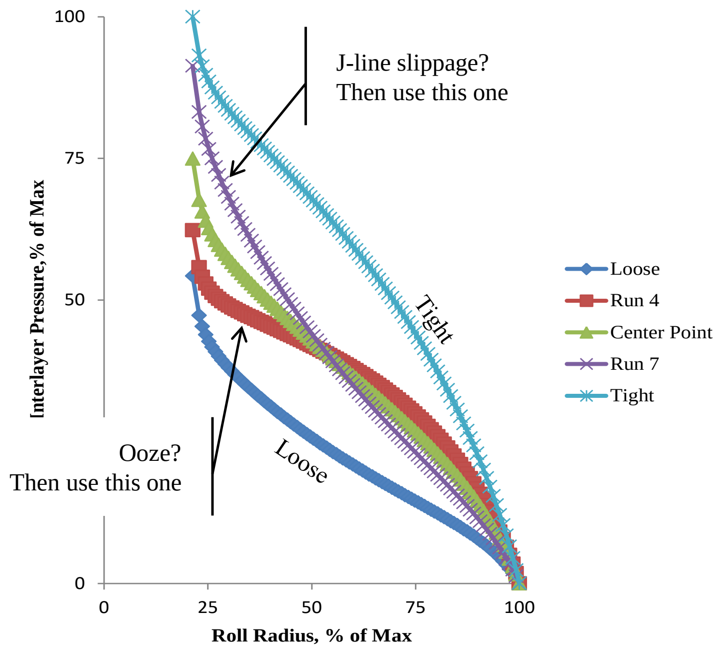

Figure 12 – Fine Tuning Parameters

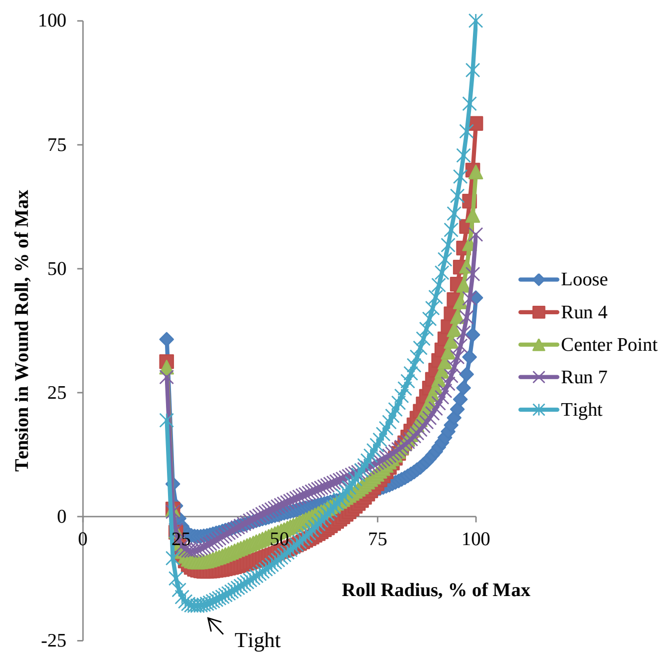

Figure 13 – Tension in Wound Roll

1D MODEL & CD VARIATION

The use of a 1D model assumes no CD variation in material or on the machine. In reality both sources of variation can be significant (especially if winding multiple rolls on a slitter). That does not mean that a 1D model cannot still be extremely useful. It's not critical that all the slit rolls have the same stress profile, only that they all fall in the defect free zone. Switching from "too tight" defects to "too loose" defects can be caused from big changes in winding parameters <u>or</u> from excessive variation eating up the defect free space (see Figure 14). Certainly excessive machine variation should be reduced before winding parameter optimization is attempted.

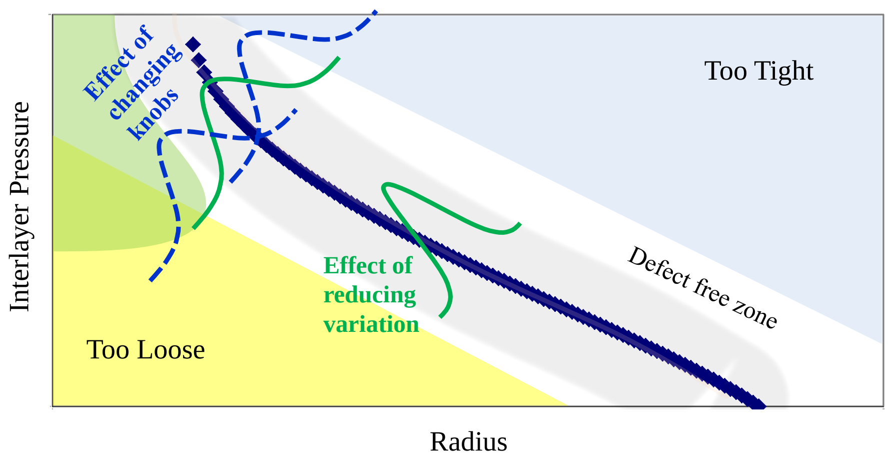

Figure 14: Variation and 1D Model

SUMMARY

Using a winding model to understand the effect of winding parameters on stresses within a wound roll reduces time and material needed to reduce winding defects. The model translates the winding parameters and material properties to stress profiles which when combined with empirical defect maps gives a picture into the wound roll. Although winding defects can be reduced without the use of a winding model, the value of its use to visualize the stresses makes the effort required to overcome the hurdles of collecting the inputs worth it.

A winding model can also be used to compare the power of different winder parameters and show how they interact. It can be used to explain why different products wind differently and are prone to different winding defects. It can be used to determine equivalent winding conditions for different winder types.

It is especially useful when balancing pressure defects with tension defects and "too loose" and "too tight" defects. A winding model in combination with DOE strategy is a powerful and efficient way to optimize winding parameters.

ACKNOWLEDGEMENTS

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