Methods Of Reducing Roll Faults Caused By Poor Thickness Profile

Dilwyn P Jones
Consultant in Materials Science and Engineering

Emral Ltd : www.Emral.co.uk

AIMCAL Technical Conferences Oct 21-4 2012
Outline

1. Wound roll defects from poor thickness profile
   – Diameter variations and gauge bands
   – Pressure and hardness variations
   – Wedged reel and poor stacking
   – Other defects

2. Solutions

3. Obtaining the underlying TD profile

4. Profile improvement methods

5. Conclusions
Gauge bands

- Ridge formation
  - Transverse direction thickness profile causes ridges in the roll
  - Increase in circumference adds extra strain to the web
  - May develop further as air is displaced from the thick bands

- Increased strain is partially set in over time
  - More is set in at elevated temperature
  - Extra strain is excess length which appears when unwound
  - Gradual recovery when left flat

© Dilwyn P Jones 2012
Radial Modulus

• Modulus of elasticity in the radial direction
  – Stack Compression Test
  – Plot stress versus strain
  – Not a “material property”
    But depends on material, thickness and surface
  – Modulus $E_r$ is the slope of the curve
  – Many materials have a nonlinear radial modulus
    Log (stress) varies linearly with strain
    Modulus proportional to stress

\[ p = K_1 \left( \exp(K_2e) - 1 \right) \]

\[ E_r = K_2p \]
Factors influencing ridges

- Ridges are higher for:
  - Greater thickness deviation
  - Higher winding tension (strain)
  - Larger Radial Modulus \((E_r, K_2)\)

- Diameter increase is lower than thickness increase
- Theory developed by TNO, Delft

\[
\left(1 + \frac{b}{\varepsilon}\right)^2 = e^{K_2(a-(1+\nu)b)}
\]

- \(a\) fractional thickness increase
- \(b\) fractional diameter increase
- \(\varepsilon\) web strain
- \(\nu\) Poisson’s ratio

There are also winding models that include thickness variations
Permissible ridge height

- Extra length in a baggy lane appears as a wave
- Example: Wavelength 0.1m, height 1mm
  - Extra length 0.03%
- Extra diameter in ridge equals extra strain in web
  - Part of this is elastic and does not contribute
  - Remainder is inelastic.
  - Land et al (2009) tested 3 papers: 40 to 50% of strain is set in after a week
- Ridge height in the example could be:
  - 0.03% for highly viscoelastic materials
  - 0.1% or higher for nearly elastic materials
- Viscoelastic webs also recover with time off the roll
- Viscoelastic setting-in and recovery are greater for:
  - Longer times
  - Higher temperatures
Extra pressure in ridges

• Extra pressure under a hard ridge can lead to other winding faults:
  – Blocking (adhesion between layers)
  – Bump in plastic films (local disruption of slip during winding)
• Pressure rise is much larger than the thickness increase
  – By a factor of $K_2$ for small thickness changes, even more at large thickness changes
  – TNO theory: $\frac{\Delta p}{p} = \exp(K_2a) - 1$

![Pressure increase in ridges graph](image)
Problems with a wedged reel

- Thickness gradient leads to diameter gradient
  - Steady state offset = $bL^2/6W$
  - Worse on narrow reels, long entry spans
- Incoming web is steered towards the large diameter side, resulting in dishing
  - Steady state offset = $bL^2/6W$
  - Worse on narrow reels, long entry spans
- A lateral force develops
  - Magnitude = $EhbW^2/6L$
  - Larger for thick, stiff, wide webs, short entry spans
    but short span theory should be used
  - Can exceed 100 kg
- This thrust load may gradually deflect the roll, chucks, sideframes etc, leading to dishing
- Sudden sideways movement can relieve the load:
  - Core shift on shaft
  - Telescope within reel
- It may damage the core or winder:
  - Axial crush of core
  - Overload of flanges, chucks, supports….
Some other faults linked to poor thickness profile

- TD wrinkles
  - Starring, spokes, polygonal roll
  - Tend to form in thin areas at the edge of the roll
  - Winding turns makes the in-roll tension negative, prone to buckling into wrinkles.

- MD wrinkles
  - Tincanning, tramlines, ribbing
  - Tend to form in thin areas away from the edges
  - Winding turns produces compression in the width direction, prone to buckling.

- Severity of MD wrinkles correlates with the thickness profile sigma
- Thinner webs are more prone to wrinkles

- Soft portion of the roll is prone to damage during handling
Solutions to profile-related faults

1. Improve thickness profile
   – Die control
   – Minimise thickness of printed features
   – Avoid printed features that stack up at particular TD locations

2. Change product structure or formulation
   – Reduce radial modulus with thinner web or rougher surface
   – Use webs with less setting in of strain (for gauge bands)

3. Reduce winding tension

4. Use a lay-on roller
   – Applies extra pressure at high spots to reduce their height
   – Prevents wound roll steering the incoming web

5. Side flanges on wound roll
   – Prevents dishing on narrower webs

6. Oscillation
   – Smoothes out narrow defects in the average TD profile
   – In blown film lines, prefer to rotate the die

7. Reduce time and temperature a viscoelastic web spends on the roll

© Dilwyn P Jones 2012
Oscillation

- Generally applied by base supplier
- Alternative methods
  1. Move web side to side using a displacement guide prior to fixed blades
     Either move the frame, or use feedback from a motorised edge sensor
  2. Move slitting blades side to side
     Either wind roll with staggered edge or guide winder to follow web edge
- How much movement?
  - Compromise between smoothing and edge trim losses
  - Typically 50 mm movement
- Frequency and shape?
  - Best smoothing from high frequency sawtooth
  - But web acquires camber in alternate directions, leading to
    - “Tree rings” and displaced turns on wound roll
    - Shear wrinkles
  - Typical use: 1 cycle every 15 mm diameter increase
    (25 mm/min for every 150 m/min line speed is quoted also)
  - Sinusoidal rather than sawtooth
Characterising profile

• Offline traces and single scans do not correlate well with the position and severity of winding faults.
• Only the thickness variations that persist over many turns of the wound roll contribute to faults.
• Profile contains several components:
  1. Underlying TD
  2. MD, uniform across the width. From periodic and random variations in machine element speed, draw ratio, temperature.
  3. MD, variable across the width, eg rocking
  4. Random variation
  5. Noise in the measurement, eg counting statistics for nuclear gauge
• For winding, underlying TD needs to estimated.
Scanning gauge

- Example: 2000m roll, 50 m/min, 2 m wide
  - 2 min scan, 200 points per scan, spot size 1 cm,
  - 40 minutes per roll
  - 20 scans per roll
  - Scan direction is 1.145° to the MD
  - Each point covers 0.5m length of web
  - Only 0.5% of the web is measured (ignoring time off the web)
Averaging the profile

- Averaging more scans gets closer to the underlying TD profile.
- Simulated results: sigma falls from 0.62% to 0.18% for 20 scans
- Underlying TD sigma is 0.14%
- Agreement with statistical theory: Variance = A + B/n
  (n.b. variance = sigma^2)
Improving the underlying TD profile

• In film extrusion, profile can be stable for many days
  – The roll average plot changes very little, sigma is constant
  – Profile control system cannot improve any further

• Some improvement methods
  – Systematic root cause analysis
    • Diagnosis chart
    • Deductions from profile measurement and actuator powers
e.g. high spots, high-low bolts, FFT
  – SMED (Single minute exchange of dies)
    • Recall previous good die bolt settings when there is a change of die,
      thickness or grade
  – Cumulative Sum to find causes of change

• Reducing MD and random components can benefit TD
Troubleshooting

• Improvement requires investigation of:
  – Gauge
  – Actuator (die)
  – Control system
  – Supplementary measurements
  – Overall process

• Web handling should ensure:
  – Web in fixed location under gauge
  – No troughs or foldovers
  – Edge trims are measured with gauge or weighed
Profile error from troughing

- The gauge measures material in beam
- Higher apparent thickness if web is inclined
- Troughs 2 mm peak to peak, 100 mm wavelength give reading 0.4% larger at B than true thickness at A
- Controller will try and maintain constant thickness
- If troughs are stationary, web will be thinner at B than A
  Resulting in thin lanes 50 mm apart
- If troughs are moving, the troughed area will be 0.2% thinner.
- These levels are significant for roll defects.
Conclusions

• Thickness variations can cause roll diameter and hardness variations, which contribute to several wound roll defects.

• Diameter variations, and hence gauge bands, can be reduced by
  – Better thickness profile
  – Lower radial modulus (product design)
  – Lower tension
  – Layon roller
  – Oscillation

• An average over many scans is needed to give the relevant underlying TD thickness profile.

• Profile improvement must look at the whole process, including web handling, not just the control system.