Wireless Measurement of Winding Roll Pressure

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Why Wi-Fi Winding Pressure Measurement?

- Many years of winding process research with nearly all confirmed by measuring internal roll pressures after winding it finished.
- Limited dynamic internal roll pressure measurements have used strain gauges on steel or aluminum cores, not in the winding roll layers.¹
Why Wi-Fi Winding Pressure Measurement?

- Winding models seem to poorly predict when cinching-induced telescoping occurs, tending to over-estimate internal roll friction and torque transmission capacity.

  - Are near-core internal roll pressure lower than models predict?
Why Wi-Fi Winding Pressure Measurement?

For products with:

- Large buildup ratios \((R_{\text{final}}/R_{\text{core}})\)
- Low core pressure (common in paper winding)
- Roll weight supported by the core (via shafts of chucks)

The rotation of the near-core layers passing through the ‘internal nip pressure’ of the roll weight over the area of the core cross-section is suspected as a near-core layer loosening effect. \(^2,^3\)
CNW: Center with Winding Nip

Roll tightness is created by a combination of the applied center torque and the surface nip load accumulated of many layers.

\[ T_{NCW,\text{WOT}} \approx T_{WH} + \mu_K N \]

- \( T \) = Tension, force/width
- \( N \) = Nip Load, force/width
- \( \mu \) = Coefficient of Friction Web Side A to B
- \( w \) = Width
- \( r \) = Radius

\[ T_{WH} = \frac{M_{CW}}{wr} \]
Calibrating Winding Torque

Initial Torque vs. Supply Pressure

- Winding Torque (N-m)
- Air Pressure to Shaft (Percent)

Equation: \( y = 4.6709x + 17.452 \)

Air Pressure to Shaft (Percent)

Tension

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Calibrating Winding Tension

Initial Tension vs. Supply Pressure

Air Pressure (Percent)

Torque

Tension

Air Pressure (Percent)

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Calibrating Winding Lay-On Nip Load

We ran with zero air pressure to winding lay-on nip roller

We used the nip roller load to calibrate the pressure sensors.

Air Pressure (Lifting)

Nip Load vs. Supply Pressure

\[ y = -9.6181x + 618.58 \]
Pressure Increase from Adding Layers

Pressure under 50 bricks
\[ P_{50} = 50W/A \]

Pressure under 10 bricks
\[ P_{10} = 10W/A \]

Pressure under 1 brick
\[ P_1 = W/A \]
Tension Creates Pressure

The tensioned web wrapped around a core creates web-to-core pressure.

- **T**, tension in force / width
- **R**, radius in length
- **P**, pressure in force per area

Pressure from one wrap

\[
P = \frac{T}{r}
\]
Is Winding Like Stacking Bricks?

**Rolls:**

\[ P_{(n=1000)} = 1000P_{(n=1)} \]

**Bricks:**

\[ P_{(n=1000)} = 1000P_{(n=1)} \]

No!
Thin Film Pressure Sensor

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<th>Tab Length (in.)</th>
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<td>(in.)</td>
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<td>52</td>
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<td>0.030</td>
<td>44</td>
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<tr>
<td>(mm)</td>
<td>(mm)</td>
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<td>(mm)</td>
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<th>Total No. of Sensels</th>
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<td>(sensel per in.²) 166.7</td>
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<tr>
<td></td>
<td>(sensel per cm²) 25.8</td>
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<table>
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<th>Pressure Ranges</th>
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</thead>
<tbody>
<tr>
<td>psi</td>
</tr>
<tr>
<td>kPa</td>
</tr>
</tbody>
</table>

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Tactile Pressure Sensor Response

\[ R \propto \frac{k}{P} \]

- Applied Pressure
  - 0 (LOW)
  - Medium
  - High

- Resistance (Ohms)
  - 0 to 10000

- Digital Output
  - 0 to 250
### Pressure Sensor Properties

<table>
<thead>
<tr>
<th>SENSOR PROPERTY</th>
<th>STANDARD</th>
</tr>
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<tbody>
<tr>
<td>Linearity</td>
<td>&lt;±3%</td>
</tr>
<tr>
<td>Repeatability</td>
<td>&lt;±3.5%</td>
</tr>
<tr>
<td>Hysteresis</td>
<td>&lt; 4.5% of full scale</td>
</tr>
<tr>
<td>Drift per log time</td>
<td>5%</td>
</tr>
<tr>
<td>Lag Time</td>
<td>5 µsec</td>
</tr>
<tr>
<td>Operating Temperature</td>
<td>15° to 140°F (-9° to 60°C)</td>
</tr>
<tr>
<td>Thinness</td>
<td>0.004 in (0.1 mm)</td>
</tr>
<tr>
<td>Sensel Density</td>
<td>Up to 1,600 per sq. in. (248 per sq. cm)</td>
</tr>
<tr>
<td></td>
<td>Pitch as fine as 0.025 in. (0.6 mm)</td>
</tr>
<tr>
<td>Pressure Range</td>
<td>Up to 30,000 psi (207 MPa)</td>
</tr>
<tr>
<td></td>
<td>(dependent on sensor selection)</td>
</tr>
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</table>
Wi-Fi Winding Measurement Experimental Setup

- Winding lay-on nip roller
- Extended paper core
- Thin film pressure sensor
- Sensor clip-on ‘handle’
- Wi-Fi unit with battery
A ‘snapshot’ of pressure was collected from all 2288 sensels at a rate of 10Hz.

A 19.2 minute run (1152s) collected 26.3 million data points with a file size of 105Mb.
This area of the sensor was outside the winding roll, = zero pressure.
Mapping Pressure over Time by Location

The pressure mapping software allows analysis by time and position.
CNW: Center with Winding Nip

Roll tightness is created by a combination of the applied center torque and the surface nip load accumulated of many layers.

\[ T_{NCW,WOT} \approx T_{WH} + \mu_k N \]

\[ \sum_i \left( \frac{T_{WHx} + \mu_k N_x}{r_x} \right) \]

- \( T \) = Tension, force/width
- \( N \) = Nip Load, force/width
- \( \mu \) = Coefficient of Friction Web Side A to B
- \( w \) = Width
- \( r \) = Radius

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Tension Increase from One Revolution

The horizontal high pressure line passing through the sensor view is from the lay-on winding nip roller.

Note: The pressure increases dramatically after the nip roller passes and one more layer is added to the roll.

Direction of Rotation
Pattern of Pressure Increase per Revolution

Pressure vs. Time

One revolution

Pressure increase of one revolution
Pattern of Pressure Increase per Revolution

*Increase from nip roller pressure footprint.*

*Pressure increases during one revolution*

*Pressure decreases during one revolution*
Film winding roll pressure increases proportional to cumulative tension over radius for the first 50mm or radial buildup.
Paper winding roll pressure increases proportional to cumulative tension over radius for only 5-10mm (25 s) before reaching a maximum value...
...then, surprisingly, core pressure decreases slightly as the roll continues to build.
Winding Film by Lateral Position vs. Paper

Core pressure at film roll edge.

Core pressure away from film roll edge.

Core pressure of paper roll.

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Winding Film by Lateral Position vs. Paper

Film roll edge pressure as 2x non-edge pressures.

Film roll pressures were 5-10x paper roll pressures.
Winding Paper Pressure vs. Lateral Position

Paper roll pressures varied 2x depending on lateral position.
Core Pressure vs. Roll Rotation (Center Support)

The rotational pressure variations were most dramatic at the roll edge.
Edge effects may have been caused by our roll-core-shaft geometry.
Are Thin Film Pressure Sensors Re-Usable?

Yes, unless...

- They are no longer in one piece
- Extremely wrinkled
- Welded together under high temperature
Summary

- Thin tactile pressure sensors and wireless data collection allows a dynamic view of the winding process.
- Near-core winding pressure can be mapped vs. both lateral and rotational position over time.
Results of Experiments

- A ‘live’ view of the once-per-revolution high pressure lane from the winding lay-on nip roller.
- The paper and film winding pressure increases with a good correlation to cumulative pressure of tension over radius.
- Paper winding rolls very quickly (20s) reach a maximum core pressure.
Results of Experiments

- Paper near-core roll pressure surprisingly decrease with roll buildup.
- Film winding rolls followed the cumulative pressure curve for many layers, but eventually deviate to lower pressures than the cumulative pressure.
- The ‘internal nip’ of large diameter, core-supported rolls was verified, showing the effects of gravity on near-core pressure vs. roll rotation.
Future Work?

- Run extended experiments (more than 4 hours).
- Compare winding with/without winding lay-on nip roller, winding at different speeds, and with two sensors simultaneously.
- Measure edge vs. non-edge effects as a function of roll, core, and shaft geometry.
- Measure near core pressure in during cinching and telescoping of low friction product.
- Measure internal pressure during unwinding.
- Install wireless pressure measurement inside a core to monitor at-speed roll transfers.
- Separate time response between roll and sensor.
Thanks

- Tekscan: Pressure Measurement Equipment, Camilo Aladro’s Time & Expertise
- WebCut Converting: Rewinding Equipment, Operator Time, Film and Paper Webs
References

