	Wireless Monitoring of Winding Roll Pressures
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EXTENDED ABSTRACT:

Winding is a dynamic process. The final roll is the product of all that happens from roll start to final cutoff. Nearly all roll measurement methods try to characterize a roll's structure after winding is completed. This is like understanding why a plane crashes from diagnosis of the debris. What winding needs is the equivalent of a 'black box.' Something that can help us understand what is happening during the winding process. This presentation will present data on a method to measure how stresses build up within a winding roll by monitoring internal roll pressure using thin resistance-based pressure sensors and wireless data collection.

WHY WIRELESS MEASUREMENT OF WINDING ROLL PRESSURE?

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

One possible explanation for cinching to occur before models predict is the ‘internal nip’ created by gravity in core-supported winding. This is especially significant for products with:

- Large buildup ratios (Rfinal/Rcore)
- Low core pressure (common in paper winding)
- High density
- 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.

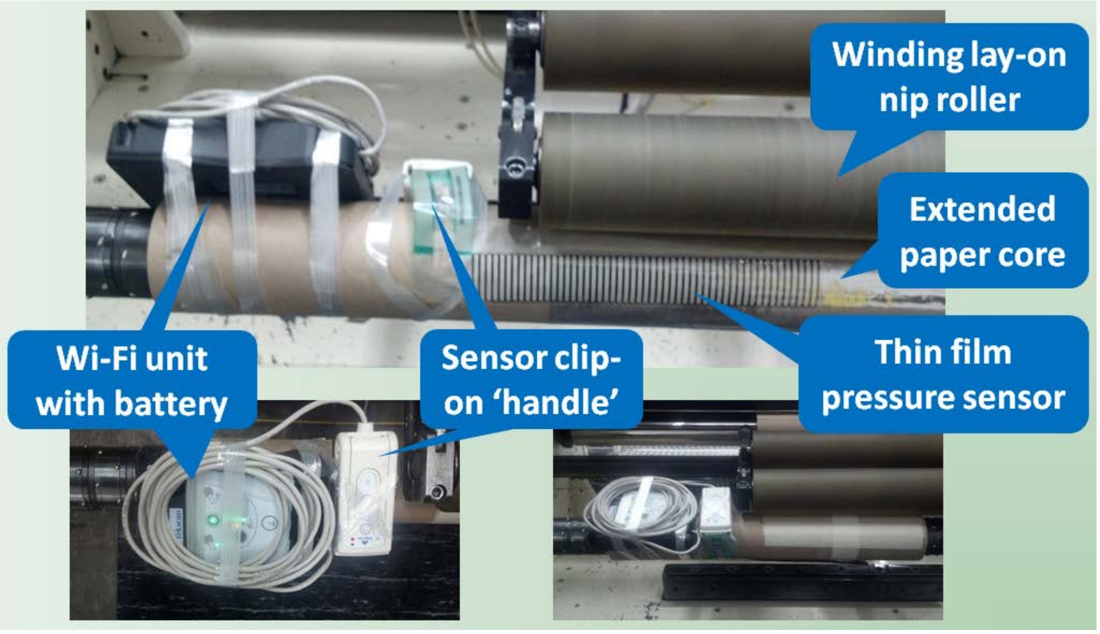
EXPERIMENTAL SETUP

To measure near-core roll pressure during the winding process, thin film pressure sensors were inserted in the layers near the core and tethered to a wireless data transmitter to send the roll pressure data to a nearby computer over Wi-Fi frequencies.

The properties of the thin-film pressure sensors are listed in the following table:

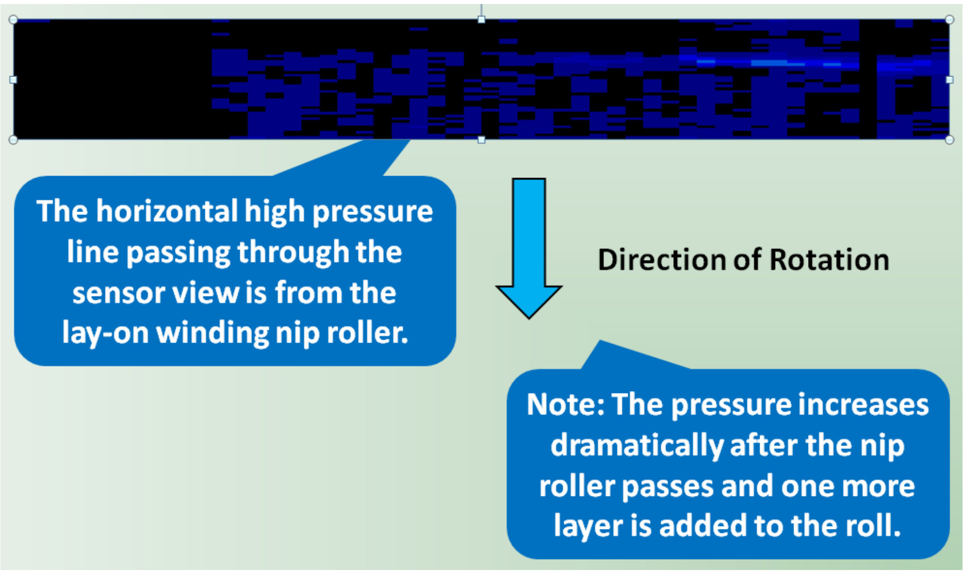
SENSOR PROPERTY	STANDARD
Linearity	<±3%
Repeatability	<±3.5%
Hysteresis	< 4.5% of full scale
Drift per log time	5%
Lag Time	5 μsec
Operating Temperature	15° to 140°F (-9° to 60°C)
Thinness	0.004 in (0.1 mm)
Sensel Density	Up to 1,600 per sq. in. (248 per sq. cm) Pitch as fine as 0.025 in. (0.6 mm)
Pressure Range	Up to 30,000 psi (207 MPa) (dependent on sensor selection)

The following diagram shows the components and layout of our wireless pressure measurement system.



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. The pressure mapping software allows analysis by time and position.

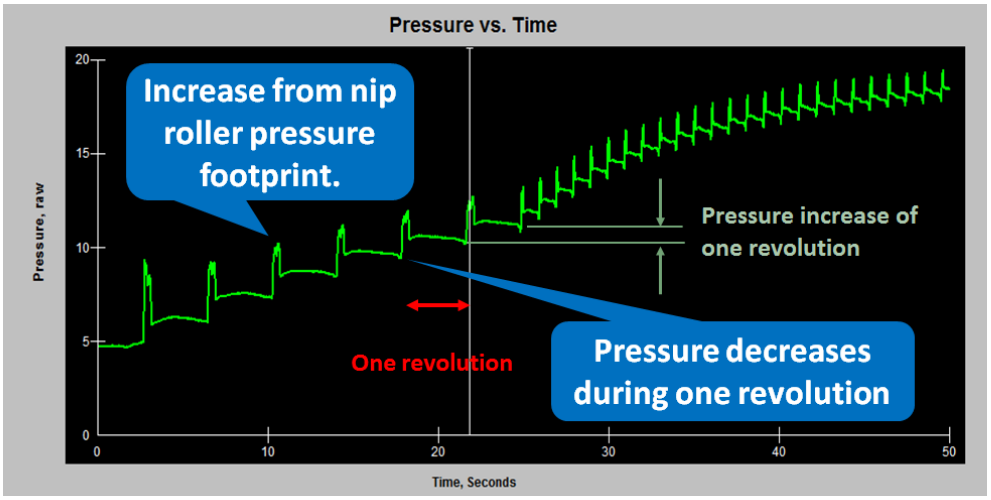
The following diagram shows the thin-film pressure sensor detecting the line-contact of the winding lay-on nip roller. The top third of the pressure map shows the low pressure before contact with the winding nip roller. The high pressure (lighter blue) line shows the line contact of the winding nip roller. The bottom two-thirds of the pressure map shows the added tension from an additional layers tension created by torque and nip load.



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.

The following diagram shows the near-core pressure increase over a series of layers added to the winding roll. Each layer shows a starting pressure, a pressure spike from the nip roller contact, a higher pressure after the contact of the winding nip and addition of one layer, then a slight decrease in pressure until the next contact with the pressure roll and next added layer. In this diagram, the time between added layers shifts as winding speed is increased.



Increase from nip roller pressure footprint.

Pressure increase of one revolution

Pressure decreases during one revolution

Near-core pressure is predicted to be a function of the tension of each layer added to the winding roll. The pressure of one layer will be the tension (in units of force per width) divided by the roll radius. The tension of an added layer when center winding with a lay-on nip roller will be a function of web handling tension created by winding torque and nip-induced tension created by the nip load proportional to the web's side A to B kinetic coefficient of friction.

$$T_{NCW,WOT} \approx T_{WH} + \mu_K N$$

A straight cumulative model, with not account of tension losses form core or roll layer compression, would predict a cumulative core pressure from the sum of pressure created by all the layers tension divided by radius.

$$cumP_{CORE} = \sum_{1}^{i} \frac{\left(T_{WHx} + \mu_K N_x\right)}{r_x} ?$$

T(NCW,WOT) = Tension of Nipped Center Winding in force per width

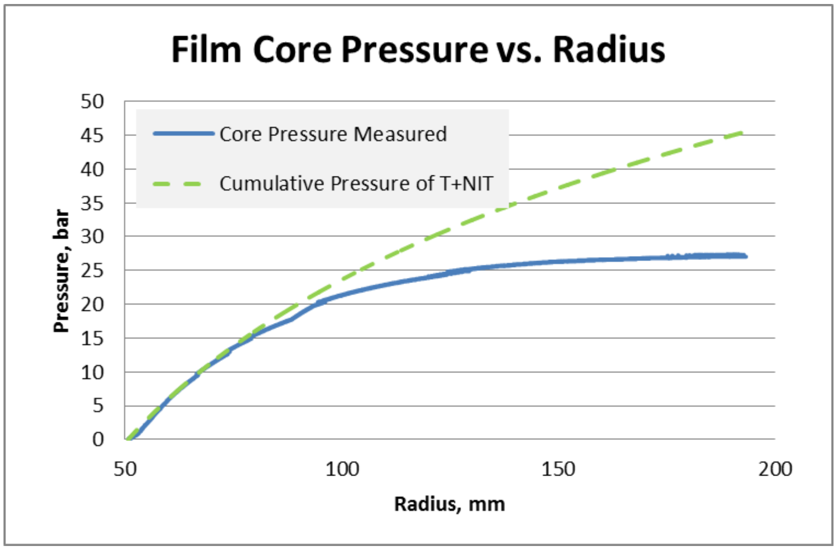
T(WH) = Tension of Web Handling upstream of winding in force per with

μK = Kinetic coefficient of friction, web side A to B (dimensionless)

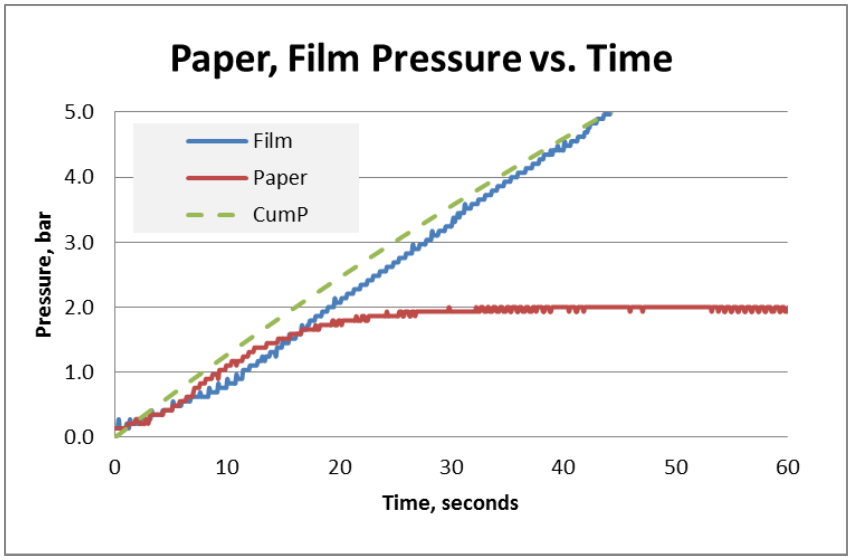
N = Nip load in force per width

r(X) = Radius, units of length

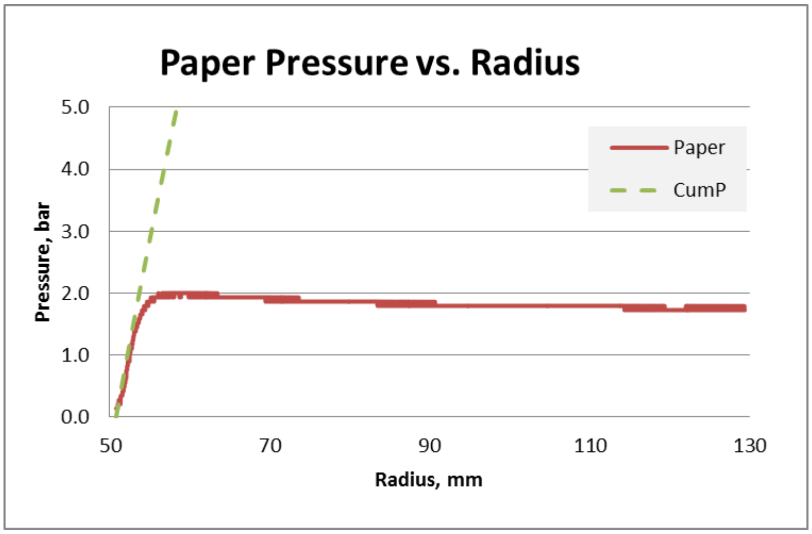
cumP(CORE) = Cumulative Pressure at the roll's core, units of force per area



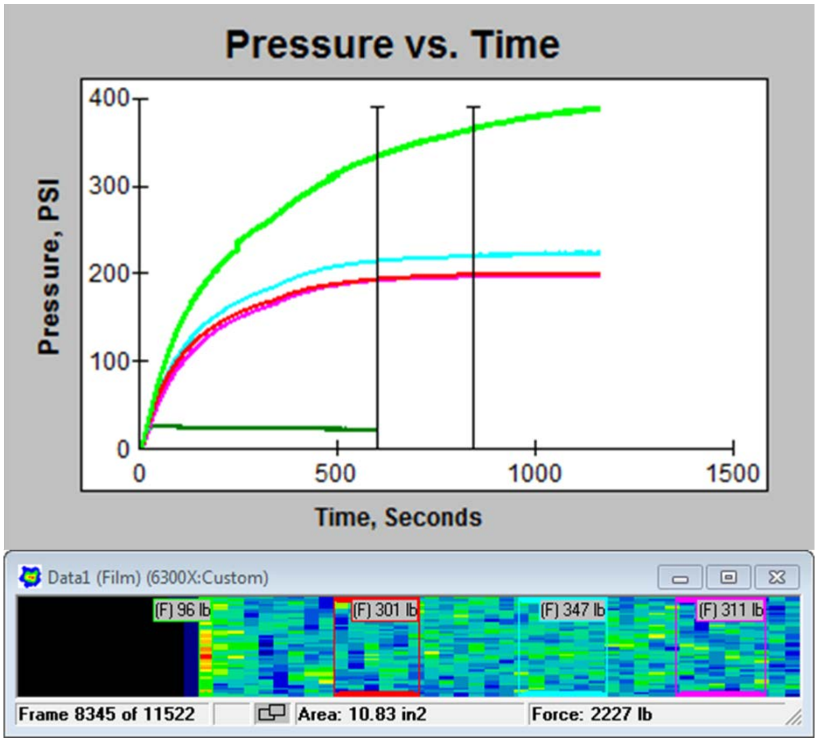
Film winding roll pressure increases proportional to cumulative tension over radius for the first 50mm or radial buildup. The pressure then increases at a rate slower than cumulative tension over radius due to core and near-core layers radial compression.



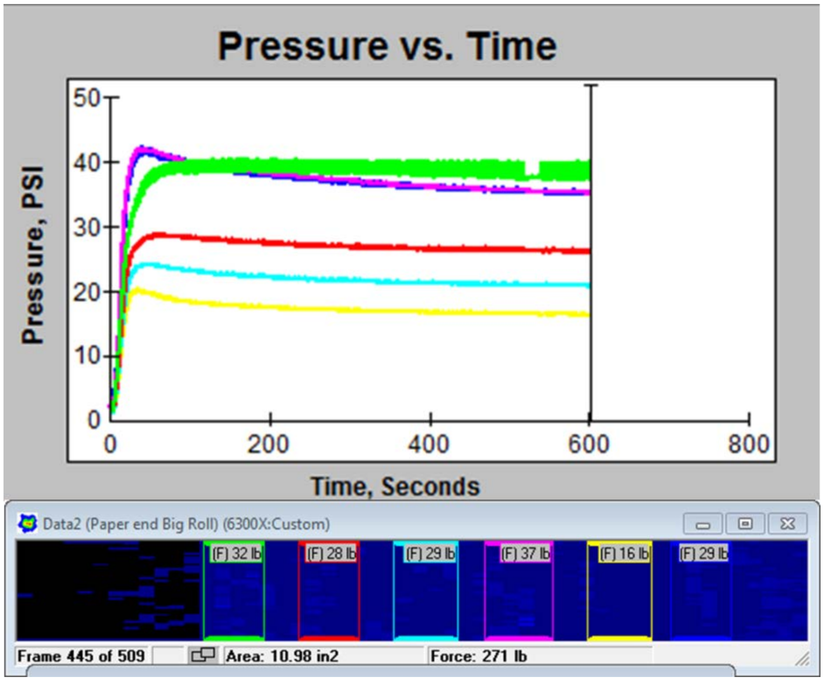
Paper winding roll pressure increases proportional to cumulative tension over radius for only 5-10mm (25 s) before reaching a maximum value then, surprisingly, core pressure decreases slightly as the roll continues to build (See diagram below).



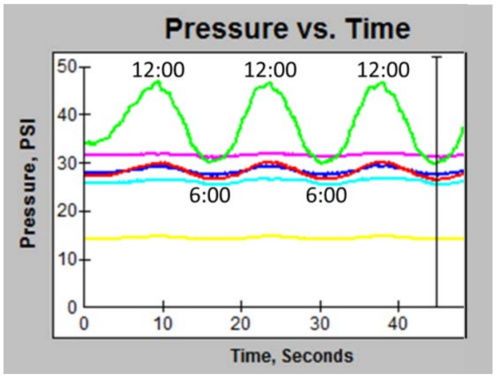
The thin-film pressure sensors map more than just average pressure. The pressure data can be analyzed by lateral or rotational position vs. time. The following diagram shows the near-core pressure of a film roll.

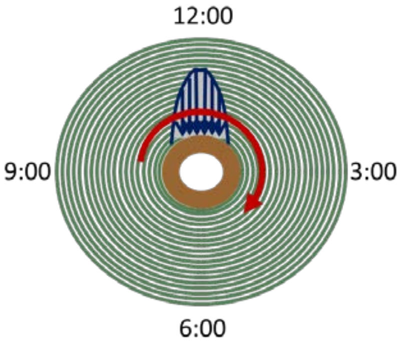


Film roll near-core edge pressures were two time higher than non-edge pressures. Film roll near-core pressures, for similar winding conditions, were 5-10x paper roll pressures.

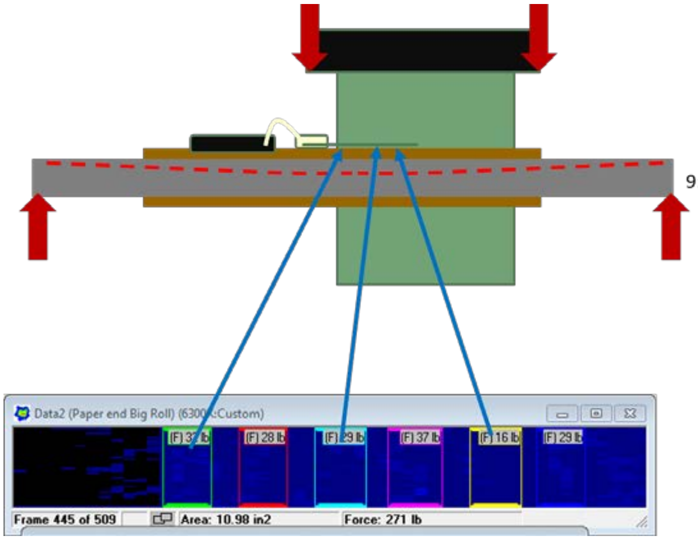


Paper roll pressures varied two to one depending on lateral position.





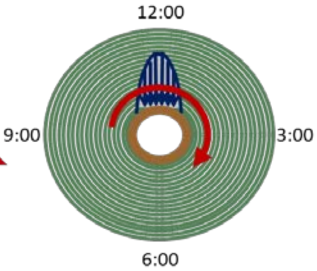
In our large paper rolls, the near core pressure was shown to be a strong function of rotation position. When the pressure sensor was at the top (12:00) position of the core, the pressure was higher than when it was at 3:00 or 9:00. When the pressure sensor was at the bottom (6:00) position of the core, the pressure was lower than when it was at 3:00 or 9:00. This rotation-position pressure variation was more significant at the roll's edge.



Frame 445 of 509

Area: 10.98 in2

Force: 271 lb



The near-edge increased sensitivity may be cause by the deflection and geometry of our roll, core, and shaft. Future experiments could separate rotation-related near-core pressure variations from roll-core-shaft geometry and gravity.

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 increase with a good correlation to cumulative pressure of tension/radius.
- Paper winding rolls very quickly (20s) reach a maximum core pressure.
- Paper winding near-core pressure surprisingly decreased slightly 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.

Acknowledgments

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References

1. Lucas, R.G., "Internal Gearing in a Roll of Paper", TAPPI Finishing and Converting Conf. Proc., October 1974.
2. Hussain, S.M. and Farrell, W. R., "Roll Winding — Causes, Effects and Cures of Loose Cores in Newsprint Rolls", TAPPI Journal May 1977, Vol. 60, No. 5
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