Making Sense of the Noise

Finding and Eliminating Variation in Roll-to-Roll Processes

AIMCAL Web Coating & Handling Conference
October 28-31, 2018 | Phoenix, AZ
Objective

- Identify the source of machine and cross-machine direction coat weight variation in a Pilot Line
  - Current slot die coating line capabilities for coat weight uniformity
    - MD: +/- 5-10%
    - CMD: +/- 2%
    - Backing roll and TWOSD processes
  - The suspects:
    - Speed Control
    - Tension Control
    - Fluid Delivery Control
  - The plan:
    - Current capabilities vs. Necessary capabilities

- Develop a solution to improve the MD and CD coat weight variation to +/- 1%
Experimental Outline

- Run a set of ladder studies:
  - Speed
  - Tension
- Develop designed factorial(s) to study the variables
- Analyze the experiment(s)
- Data acquisition and analysis tools:
  - SCADA package for data collection
  - PLC and drive trending
  - Statistical software
- Experimental execution, data collection, analysis, and prepare conclusions and recommendations
Coating Line Layout
Initial Analysis

- **Speed Control Ladder Study**
  - Full range of **pilot line speeds** vs. motor speed error (scaled for clarity)
  - Current coating motor speed error range: ~ 5-20%
  - Desired motor speed error range: ~ 0.30%

![PC Line Speed vs. Motor Percent Error](chart.png)
SCADA Software

- What can it do?
- How can we use the information?
SCADA Real-Time Data Trending
SCADA Real-Time Trends

- Error as a function of tension setpoint
- Error % increases with decreasing tension setpoint
- Independent of speed
- Independent of rewind diameter
- Online, real-time trouble shooting
- Data output to .csv, etc.
Factorial DOE and Results

- **¼ Fraction Factorial**
  - 6 factors (line speed, tension, tension mode, nip pressure, nip position, substrate type)
  - 2 levels
- The variability within the speed overpowers almost all of the other factors with respect to speed control
  - 3-5X stronger
- The variability in tension was affected by:
  - Tension set point
  - Tension mode (ratio or tension)
  - Nip position (open or closed)
  - Line speed
Effect of Speed on Variability

Pareto Chart of the Standardized Effects
(response is Ref Chill Speed, $\alpha = 0.05$)

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Factor Name
- A: Line Speed
- B: Tension
- C: Tension Mode
- D: Nip Pressure
- E: Nip Position
- F: Substrate
Effects on Tension

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(response is Chill T, $\alpha = 0.05$)

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Initial Conclusions

- Fix the speed control first
- Retest speed and tension control
- Tune control loops
Implementing Speed Control Solutions

- Made market-based decision to reduce pilot coater line speed via gear reduction to allow higher motor speeds (better resolution)
  - Designed and installed new sheaves and belts to produce 3:1 gear reduction without compromising machine’s original drive layout
  - New top line speed: 650 FPM

- All motor encoders upgraded to sin/cos encoders to improve resolution throughout entire motor speed range
  - Old encoders – 1,024 PPR (Pulses Per Rev)
  - New encoders – 1,048,576 PPR
Motor Speed Control Review

- Target coating speeds on pilot line are 1, 3, and 5 MPM
  - Motor error is around 1-2%, 0.4-0.6%, and 0.25-0.39% respectively for those speeds
  - Previous errors of 10-20%, 3-6%, and 2-4% for same respective line speeds

- Result is a 10X improvement in motor speed control

- At new top line speed of 650 FPM motor errors are in range of 0.01-0.04% error
  - New top line speed still in line with current market demand
Motor Speed Tuning

- All motors tuned under no-load conditions with new encoders
- All motors tuned under load for inertia mismatches
- Speed control ladder study (Focused on low speeds 0-20 FPM)
Study of Tension Control

- 3 modes of control
  - Non-extensible
  - Extensible
  - Extensible plus Shrink-Compensation
- Nip pressure
- Nips open or closed
- Tension range
- Pilot line tension zones
Tension Control

- Obtained new baseline for current tension control (separate but directly related to speed control)
  - Currently analyzing trends to begin optimizing tension control strategies

- +/- 1% MD/CMD Uniformity still end goal
  - Resume testing with updated speed control – find new current uniformity limitations
  - Reach uniformity goal with further tension control tuning
Tension Oscillations

Extensible Speed Data
Run Sample #5

Line Speed (fpm)

InfeedFpmPV
GravureFpmPV
ChillFpmPV
Conclusions

- Speed control strategy was a success and gives pilot coater line much greater control in speed range that customers typically request for coating tests.

- New “standard” set in terms of MD/CMD coating uniformity with new speed control.
  - Upgrades and study results led to consistent and repeatable coating uniformity control to within +/-1% for MD and XMD.

- Continued instabilities and measurement system limitations prevent good process capability at the new standard.

- Improvements in process capability will require further improvement in filtering noise from the input materials and measurement systems.
Conclusions

- What else did we learn from this case study and exercise?
  - Deeper understanding of how the pilot line works
  - The ability to react to problems that arise and solve them faster
  - Identify areas for future improvement
- Tension control tuning to offer further improvement in both MD/CMD battery coating uniformity
- Additional simplification of controls possible?
Questions?