Extracting periodic patterns in steel

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AI-ROT

- Research project funded by Academy of Finland
- Aims to improve product lines with focus on rotating components
- Investigates new methods for machine direction analysis
- Industrial partner SSAB
Steel strip production process

Online measurement of steel strips

Some quality parameters:
• Centerline thickness
• Cross profile measurement
• Crown and wedge
• Edge-drop
• Strip width
• Strip contour
• Strip temperature cross profile
Machine direction analysis

• Rotating machine elements cause imperfections in the end product corresponding to their rotating speeds:
  ▪ Roundness errors of rolls
  ▪ Unbalance
  ▪ Vibrations
• Obtain machine direction data with online system or laboratory analyzer
• Rotating speeds of components are known, repeating patterns can be separated
Modeling the thickness variation from single roll with sinusoids

Stationary: \[ x(n) = \sum_{l=1}^{L} A_l e^{j\omega n} \]

Varying amplitude: \[ x(n) = \sum_{l=1}^{L} A_l(n) e^{j\omega n} \]

Varying frequency: \[ x(n) = \sum_{l=1}^{L} A_l e^{j\phi(n)}, \quad \phi(n) = \phi(0) + \int_0^n \omega(\tau) d\tau \]
Proposed procedure for extracting the patterns

1. Estimate the frequency curve for each roll assuming constant amplitude-varying frequency model
2. Estimate the varying amplitudes during the rolling process using result from step 1
3. Resample and synchronize the patterns to angular domain
Frequency profile estimation with nonlinear least squares (NLS)

- The line speed in the end is known
- Assumption that all rolls are rotating at speed proportional to the line speed
- Maximizing the NLS cost-function yields the relationship term

\[
Z_L(k) = \begin{bmatrix}
e^{ik\varphi(0)} & e^{ik2\varphi(0)} & \cdots & e^{ikL\varphi(0)} \\
e^{ik\varphi(1)} & e^{ik2\varphi(1)} & \cdots & e^{ikL\varphi(1)} \\
\vdots & \vdots & \ddots & \vdots \\
e^{ik\varphi(N-1)} & e^{ik2\varphi(N-1)} & \cdots & e^{ikL\varphi(N-1)}
\end{bmatrix}
\]

\[
\varphi(t) = \varphi(0) + \int_0^t \omega(\tau)d\tau
\]

\[
J_L(k) = x^T Z_L(k)[Z_L^T(k)Z_L(k)]^{-1}Z_L(k)^T x
\]

\[
\hat{k} = \arg \max_k J_L(k)
\]
NLS spectrum for one strip

Each red line represents either work or backup roll in the finishing mill
Amplitude estimation with LMS adaptive algorithm

Design vector: \[ z(n) = [e^{\text{i}k\varphi(n)} e^{-\text{i}k\varphi(n)} e^{2\text{i}k\varphi(n)} e^{-2\text{i}k\varphi(n)} \ldots e^{L\text{i}k\varphi(n)} e^{-L\text{i}k\varphi(n)}] \]

Estimated roll pattern: \[ y(n) = a(n)^\text{H} z(n) \]

Error signal: \[ e(n) = x(n) - y(n) \]

Update amplitudes and phases: \[ a(n + 1) = a(n) + \mu e(n) z(n) \]
Amplitude estimation for simulated signal
Conclusion and future research

- NLS can be used to refine the estimated frequency profile
- Estimating the amplitudes and phases of the rolls using the LMS algorithm
- Extracting average patterns for the rolls using real data
- Quantifying the contributions of each roll to propose scheme for intelligent service scheduling based on development of individual roll patterns
Thank You