Drive Response Requirements for Web Handling

Clarence Klassen. P. Eng. (ON)
KlassENgineering Inc.
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Introduction

- Drive Speed and Tension Regulators are tuned.
- We consider these to be second order systems.
- More than one regulator is used in each drive.
- The metrics for a tuned regulator are the regulator response and overshoot (zero).
Vibrations and Frequencies

- We are interested in the frequencies associated with control.
- These are vibrations.
- At least two of our senses have a great deal to do with vibrations.
What May Be Vibrating?

The process variable we hope to control.

- Temperature (°C)
- Flow (L/sec)
- Position (m)
- RPM (radians/second)
- Torque (N-m)
- Tension (N/m)

The units of vibration frequency are (radians/second).

*Vibration is NOT the same as RPM*
Tuning is “Dampening the Vibration”

- We don’t want our process variables to vibrate.
- We want our systems over-damped so they do not vibrate.
- OR we want the vibration frequency so high it is not a problem.
Definitions

- Second Order System
- Process Variable (PV)
- Setpoint (SP)
- Control Variable (CV)
- Dead Time
- Overshoot
Over Damped or Critically Damped Response
Definitions (cont’d)

- Oscillatory
- Period of Oscillation (sec)
- Frequency of Oscillation (rad/sec)
- Instability
- Response Time (sec)
- Response (Bandwidth) (rad/sec)
- Settling Time (sec)
Under Damped and Critically Damped Response
Control System
Regulator and Plant
Definitions (cont’d)

- Regulator
- Gain
Definitions (cont’d)

- Lead
Ideal Regulator Response

![Ideal Response Diagram](image-url)
Practical Regulator Response
Tune Spindle B speed regulator for 1.4 radians/second. $K_p=10.5$, $T_i=0.38\text{sec}$
What regulator response is required or desired for speed regulators?

Some answers from experts are:

- Use the drive default settings (5 radians/second)
- Just perform the auto tune (no metrics)
- Each drive tuned as fast as possible (1 to 5 radians/second)
- Same tuning as the previous similar line. (no metrics)
- All drives tuned the same as the drive with the slowest response (2 radians/second)
- Modern drives don’t need to be tuned. (no metrics)
- Brand X drives are always tuned too stiffly or too aggressively (no metrics)
- The drive is not responsive enough (no metrics)
- The drive should be tuned with 5 to 10% overshoot for better response to web disturbances (no metrics)
Assume a 5 rad/sec Speed Regulator

- A 5 rad/sec speed regulator response is a typical default value for drives.
- This is achievable for low inertia sections with quality speed reducers and couplings such as used in plastic film
- This is not achievable for many wide machines (5m)
The speed regulator must be fast enough to perform within the time constraints of a turret winder.

Assume a 5 rad/sec speed regulator and a 5 second index time.
Response and Turret Winders

- Assume a 5 rad/sec speed regulator and a faster turret winder with a 1 second index time
Tension Regulators have 1/3 the Response of the Speed Regulator

- The tension regulator response is limited to 1/3 to 1/10 the response of the speed regulator.
- For a 5 rad/sec speed regulator, the fastest theoretical response of the tension regulator will be 1.3 radians/second.
Unwind Splice

- An unwind splice creates a tension disturbance which affects all sections in the line.
- Even though the splice is complete in a fraction of a second, the tension regulators recover using their response.
- With a 1.3 rad/sec tension regulator, the settling time will be 3 to 4 seconds.
- The web may see wrinkling and other defects during this interval.
- The web will also be more prone to a break during this interval.
Limits to Speed and Tension Regulator Responses

- Backlash
- Belts Slipping
- Torsional Resonance
- Power Limited
- Noise in the control system
- Filtering
- Tension Response limited by Speed Response
- By Design

http://upload.wikimedia.org/wikipedia/en/2/2e/Backlash.jpg
Example – Trim Nip with Fabric

- Trim Nip with fabric $K_p=0.5$, $K_i=0.1$ 1/s, $K_d=0.1$ s.
- Increase in tension was good. Notice the Dead Time
- Decrease in tension has undershoot.
- Time constant 1.6 sec, Response = 0.63 radians/sec
Example – Trim Nip with Laminated Fabric

- $K_p=0.5$, $K_i=0.1$ 1/s, $K_d=0.1$ s.
- Time constant 2.0 sec, Response = 0.50 radians/sec
What Responses do we see in Web Handling lines?

<table>
<thead>
<tr>
<th>Web</th>
<th>Drive</th>
<th>Speed Reg. Response rad/sec</th>
<th>Tension Reg. Response rad/sec</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metal Rolling</td>
<td>Vector or DTC</td>
<td>10</td>
<td>3.3</td>
</tr>
<tr>
<td>Paper Mills</td>
<td>Vector or DTC</td>
<td>0.3 to 1.0</td>
<td>0.3</td>
</tr>
<tr>
<td>Converting lines</td>
<td>Vector or DTC</td>
<td>1.5 to 5.0</td>
<td>0.5 to 1.5</td>
</tr>
<tr>
<td>Converting lines</td>
<td>Servo</td>
<td>10 to 120???</td>
<td>3 to 40???</td>
</tr>
<tr>
<td>Paper Mill Best Case (Unwind on Coater using dancer)</td>
<td>DC</td>
<td>0.3</td>
<td>10.0 (into torque regulator 1996)</td>
</tr>
<tr>
<td>Converting lines Worst Case (laminator for fabric and poly)</td>
<td>Vector or DTC</td>
<td>5.0</td>
<td>0.001 (purposely tuned this slowly-no justification available from the drive rep.-2011)</td>
</tr>
</tbody>
</table>
What Operators Want

- *The drive is not responsive enough!*
- Threading
- Speed Changes
- Closing Nips, Applying Coating
- Turret Indexes
Giving Operators What They Want

As Found
0.4 rad/sec
Not Exponential

As Left
1 rad/sec

Learning While Having Fun!
When Drive Response is Important

- A new line is not as responsive as an older line.
- Following a drive upgrade, the line is not as responsive as it was.
- Guidance is needed for a new process.
Regulator Response information for web handling is not published.
Regulator theory is well known – 4th year controls class.
Drive vendors know their regulator response and tuning procedures and targets.
Sophisticated producers know the regulator responses on their lines.
Many Web Handling OEM’s, producers and drive vendors do not have good guidance for tuning drives for web handling lines.
Conclusions

- Operators would like faster response for easier operation of the line.
- Managers like faster response because it reduces waste due to tension variations.
- Maintenance likes slower responses because equipment lasts longer.
- Maintenance likes faster responses because they like satisfied operators.
- We can’t arbitrarily increase response without consequences – there are mechanical limits.
- How responsive is responsive enough?
- I suggest 5 rad/sec for speed and 1.3 rad/sec for tension as generally acceptable values. Many web handling drives do not achieve these values.
- Discussion, experiences and opinions are welcome.
- Metrics will make the discussion meaningful.
Questions???