Good Winding Starts - the First 5 Seconds - Part 2 Drives
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Abstract:

This is the second part of the "Good Winding Starts" presentation. Here we discuss the drive system and its requirements for good winding starts.

We begin with the preparation for a good start.

We will also discuss the dynamics introduced by the drive system in accelerating the roller. The drive discussion will include drive tuning, stall tension, S Ramp, initiating the diameter calculator and transitions in tension.

We will specifically consider the case of a slitter/winder which stops for each new roll. Mention will be made of differences when considering turret or other winders with continuous high speed cutovers.

Definitions

Closed Loop Tension Control – A transducer such as load cell or dancer position is used to measure and affect the torque or speed to control tension.

Draw – A percentage speed difference introduced between drive points resulting in web tension.

Friction Compensation – compensation for bearing and speed reducer friction.

Inertia Compensation – compensation for the torque needed to accelerate or decelerate product rolls or rollers in the line.

Open Loop Tension Control – A fixed speed difference or fixed torque is used to establish satisfactory tension.

Stall Tension – a reduced tension setting used when the line is stopped or stalled.

Tension Zone – two driven points with traction establish a tension zone.

Traction Point – a point (nip, unwind, spindle, S Wrap, vacuum roller, etc.) on the line with good web traction. This may be driven or controlled with a brake.

Windage Compensation – compensation for friction due to air motion with the web, roller surfaces or fans in the motor.

Zero Speed – lowest speed which can be sensed by the drive. Used to set brakes, de-energize the motor, call for stall tension.

Introduction

The instant of starting a slitter/winder is very easy to define for the drive system. It is the instant the thread or run pushbutton is pressed. This may be starting at a core, or restarting after a splice. As mentioned in the earlier, related paper, to get a good start we need good preparation and then good execution.
The drive system is needed for speed and for creating machine direction tension. Machine direction tension variations may present as sheet wander (cross machine variations). Tension variations may also contribute to many web defects such as blocking or wrinkling. A Tension Zone is established between the two traction points consisting of the winding drum and the unwind brake. The drum is the line speed master. The brake establishes tension against the rotating drum or stall tension against the drum brake or the web clamp.

Slitter/winders cannot physically jump to running speed on starting. The transition must be smooth and coordinated.

![Diagram of Slitter/Winder](image)

**Figure 1 Diagram of Slitter/Winder**

**Pre-Start Preparation**

If the start begins with pressing the thread or run button, it is necessary to prepare in advance. The unwind diameter must be preset to the actual unwind diameter. The web must be square, centered and made taut. Tightening the web is very difficult to automate because until the web is taut, the load cell reads zero tension. Tension for the example would be established by rotating the unwind in reverse.

As soon as the web is taut, tension control can be enabled. This can be manually enabled or automatically enabled when tension is detected by the load cell or dancer position. Holding tension against a brake or web clamp while stopped is often called Stall Tension.

**Stall Tension**
Stall Tension operation must be specified based on the slitter/winder and the web being wound. By definition the web is at zero speed for stall tension and the stop is maintained usually by a mechanical means such as a brake or friction at some point on the web path. Stall tension is achieved with at least one drive activated and pulling against the stopped web. Many times the web is clamped at the windup and the unwind drive is enabled to establish tension and to control it at the stall tension setpoint.

Under some circumstances zero speed may be achieved by the master motor running at zero (detent) speed. If there is no means of positively holding the web, such as a web clamp, brake or layon roller, stall tension controlled by the unwind must exactly balance the master.

Stall tension should be used only when there are valid reasons for using it. Stall tension should be set just low enough to prevent pulling the web backward. It cannot tear the web from the core. Stall tension must be low enough to prevent pulling a splice apart.

The drive does not require stall tension. Stall tension should be as near running tension as possible so long as the high stall tension value does not create one of the problems listed above. A high stall tension will reduce the transition to running tension once the slitter/winder is accelerating.

Drive speed control is not suitable for stall tension. The unwind drive is normally operated in torque mode when stopped. If speed control is used, the web tension may be undefined. The unwind drive can be engineered to stay in tension through torque control or transition to tension through speed while accelerating.

The stall tension may be maintained until the slitter/winder is running at slightly greater than thread speed.

A very few older drives fault if stall tension is left on for more than a few seconds.

Tension Measurement

Load cells and dancers do not read tension correctly at zero speed. Roller eccentricity and static friction have a big effect on the measured tension. Similarly dancers are plagued with stiction. Therefore stall tension is normally programmed as an Open Loop Tension Control using a torque setpoint. The load cell measures tension, but does not control tension until the slitter/winder is started.

The tension sensors are enabled at a certain speed once the slitter/winder is started. This is called Closed Loop Tension Control. Generally the speed is just above thread speed such that

Mechanical Brake Control

Often both the master and unwind drives have mechanical parking brakes.

On stopping and starting, brake timing is crucial. If the brake is dis-engaged late, the drive will start with excess torque and will lurch forward. If the brake is dis-engaged before the drive has built up torque, the web may move backwards and affect the quality of the slit.

Once the second brake or web clamp is activated, web tension is locked in and the drive is incapable of adjusting tension. Most new drives incorporate brake coordination. Several parameters including brake release and engage timing and the torque required when the brake is released must be entered. While brake control for suspended loads (such as a turret with a large roll on one side, lifting table or a crane)
may be required to eliminate gravitational hazards, brake control for a balanced slitter/winder is used to minimize tension spikes on starting and stopping. The slitter will not generally require formal torque proving and proving the condition of the brake with sensors.

**S Ramp**

Instantaneous speed changes are not physically possible – Some carnival rides give the idea of very fast acceleration.

Constant Acceleration – apple falling from a tree. There are jerks involved.

S-Curve or S-Ramp by Otis/Ward Leonard for elevators until the 1980’s[1]. Acceleration is increased and decreased gradually. Consider 3 speed related functions:

*Velocity* - important to productivity, must be closely matched between sections

*Acceleration* - 1st derivative of velocity, apply gently and ramp

*Jerk* - 2nd derivative of velocity. Jerk is a good name. The jerk may be large and is present for the entire rounding period. Without the S Ramp, jerk approaches infinity.

*Length* - integral of velocity – not important to the present discussion

Drives can follow a steady speed or velocity reference with zero error.
Drives cannot follow a changing velocity setpoint (acceleration) without an error.

Below is a graph of the actual speed response of a drive to a step in speed. The shape for a well tuned drive is an approaching exponential. We note that in the steady state the speed matches the setpoint. A less well tuned drive will have some overshoot (underdamped) or may be much slower to respond (underdamped). Dynamic response to a step is a very useful diagnostic for determining the drive is performing adequately for web handling.

![Graph of Step Response](image)

**Figure 3 Graph of Step Response**

Below is the response of a drive to a linear ramp. We note that in the steady state (acceleration), the speed lags the setpoint. The degree of lag is related to the response of the drive to a step change as listed above. During the dynamic (starting) portion, the drive is responding to a changing acceleration demand with an exponential response. We note that the drive follows a ramp better than it follows a step. We also note that the Jerk approaches infinity at the start and end of the ramp. Note: the response is for a drive that is not underdamped.
Figure 4 Graph of Linear Ramp Response

Below is the response of a drive to an S Ramp. We note that the S Ramp has more changes, but the changes are each more gentle than for a step in speed or a linear ramp in speed. The S Ramp takes more time to change speed than a linear ramp.

Figure 5 Graph of an S Ramp Response
We also note that to establish tension we need to consider two traction points, which may include drive, brakes or clutches. Thus all the discussion about dynamic response affects at least two drives.

When commissioning a drive, the master S Ramp is the base line for the entire line. All drives are individually compared with the S Ramp (S Ramp - drive actual speed = speed Error). The drive can have feed forward techniques such as Inertia Compensation and Friction and Windage Compensation applied to minimize the error. Finally, the important issue is the speed difference between adjacent traction points. The speed difference between adjacent drives is known as Draw, and draw is directly related to tension. Thus dynamic speed differences create dynamic tension variations. On a percentage basis, speed errors create greater tension variations at low speed.

Inertia Compensation

As shown above, drives cannot exactly follow a ramp. The speed difference compared with the master S Ramp can be overcome using inertia compensation. Inertia Compensation is tuned to overcome this difference for steady acceleration. Inertia compensation also helps during the rounding portion.

Figure 6 Graph of an S Ramp Response with Inertia Compensation
Tension is created by small differences (delta) in speed between traction points. It is trivial to eliminate speed differences at a steady line speed, but is more difficult during speed changes.

The speed error during acceleration is related to the speed regulator Bandwidth (BW) measured in radians/second. I suggest all drives affecting machine direction tension be tuned for the same BW. If auto tuning of the drives is use, verify the actual resulting BW with a trend. Suggested BW was presented in a previous AIMCAL conference as 5 radians/second. [2].

There are several methods of applying inertia compensation, but in most cases the required (measured) acceleration torque for the roller without web is summed into the torque reference. The measured
acceleration current is multiplied by the normalized S Ramp rate output signal so that it is applied only during acceleration or deceleration.

A previous AIMCAL presentation discussed methods of setting the inertia compensation [3].

Inertia compensation is good during steady acceleration, but is not perfect during rounding.

![Figure 7 Tracking between S Ramp and Measured Speed](image)

**Drive Coordination**

Six drive coordination problems add to speed differences between drives, thus tension variations. These are important fine points.

1. Use an S Ramp.
2. Set Inertia Compensation.
3. Bandwidth of the speed regulator should be high and matched for all web transport drives.
4. Latency in communications between drives is also important when considering matching the velocity of drives. All drives must receive acceleration commands at the same instant. One drive accelerating before another creates a speed difference. A missed speed change update to one drive will create a short lived speed difference.
5. Tach or encoder filtering prevents setting inertia compensation accurately. To make drives look good, the velocity is often filtered. This filtering affects measurements used in setting inertia compensation. Consider eliminating the filtering during commissioning and set all drive filters the same.

**Diameter Calculation**
Errors in calculating the unwind diameter is almost always a major cause of tension variations when starting a slitter/winder. Diameter is almost always calculated by the ratio of web speed to spindle RPM. At low speed, this would result in division by zero.

Diameter must be preset before applying stall tension.

The diameter calculation is enabled at between 5 to 10% of line speed. When the diameter calculator is activated, we get a transition in diameter. This results in a speed change, torque change and tension change. This is often the largest disturbance in the first 5 seconds.

On decelerating the slitter/winder, we often see the calculated unwind diameter increasing. In many cases this is due to filtering on the speed feedback.

**Small Speed Changes**

Everyone knows that many small speed changes are better than one large speed change. Wrong. The maximum jerk is present for every speed change. In fact the worst case is a sudden acceleration followed with a deceleration before coming to steady speed.

![Small Speed Changes](image)

*Figure 8 Small Speed Changes*
Starting Timeline

![Starting Sequence]

Figure 9 Starting Timeline

We note that any transition may be responsible for a tension variation. Various transitions inherent in drives for web lines are presented below.

1. Thread - triangle acceleration - jerk is present at its maximum for the entire speed change
2. Stall tension transition to running tension
3. Open loop tension control transition to closed loop control
4. Transition to tension through speed if applicable
5. Run- S-Ramp round in. Inertia compensation makes an attempt to compensate during the rounding time.
6. Steady acceleration - continues
7. Enable diameter calculator

Other Winder Types

Other winder types have different considerations for good starts.

In particular, turret winders do not typically undergo speed changes while producing saleable rolls. Therefore inertia compensation is not a big concern. All the other considerations such as latency, friction and windage compensation, determining when to active closed loop tension control and begin calculating diameter is important.

Flying splice unwinds or zero speed unwind splices also have special starting concerns. The major concerns involve accurate position sensing and control, timing of cutting and pasting actuators and determination of the optimum time to enable tension regulation and diameter calculation.

Conclusion

Beside mechanical considerations, care in commissioning the web handling drive system is very important for achieving consistently good starts. The drive technologist or engineer should pay attention to:

1. Drive network performance
2. Speed regulator tuning
3. Brake release timing
4. Inertia compensation
5. Diameter presetting and calculation
6. Minimize the number of speed changes

References

