Motion Control for Converting

And the Benefits of fully Integrated Drive Control
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Abstract

Motion control technology has revolutionized the printing industry with shaftless and synchronized drive control capability. In each and every printing sector, presses are now supplied with electrical line shafts where drives “electronically gear” the individual print units to each other.

The benefits that the printing industry has witnessed from the conversion from mechanical to electronic drive systems have been multiple. The torsion elasticity and gear backlash of the mechanical line shafts are eliminated. Up-time is maximized by the precision and speed of make-ready. Individually drive print units can be electronically decoupled and parked for plate changes on the fly, just to name a few.

Traditional converting and web handling lines have rarely utilized the same single drive / line-shaft concept that was the norm of the printing industries. Coating, laminating and converting lines feature individual machine sections such as unwinds, pull rolls, coaters, laminators and winders that are driven independently under tension or draw control. The drives that control these sections are typically coordinated with individual speed or torque control signals.

The majority of today’s AC drives and drive controllers now have the integral capability for position control and electronic gearing, high speed peer to peer networks and can utilize very high resolution feedback devices, the required basic functionality for synchronized sectional drive control.

With machine performance criteria ever increasing, what benefits can be realized by applying modern motion control technology to coating, laminating and converting lines? Are there other areas that position control capability or status can enhance and benefit the performance and functionality of converting machinery?

Introduction

Numerous benefits that can be realized by applying modern motion control technology for a wide range of converting and web handling applications. Consider just a few of the identified benefits;

- Increased stability and improved dynamics.
- Driven axes with significantly different inertias can accelerate at the same rates.
- Significantly improved tension control accuracy.
- Improved draw control precision and repeatability.
- Improved registration control in coat to register.
- Improved splicing and tail control accuracy over PLC time based systems.
- Integration of motion based and web coordinated drive applications.
- Use of virtual masters verses following noisy or unstable actual setpoints
Motion Based Web Control

Improved System Dynamics, Stability & Disturbance Rejection

In the drive controller with regulation by velocity loop, the system dynamics and stiffness are determined by the proportional gain and the integral time shown in the following equation:

\[ c_{pos}(s) = \frac{K_p}{T_N} \]

With the addition of the position loop the dynamic stiffness value is augmented with a term containing the position loop gain, as follows:

\[ c_{pos}(s) = K_p \left( K_v + \frac{1}{T_N} + \frac{K_v}{T_N 2\pi f} \right) \]

The position control loop therefore provides increased system stiffness, improved stability and dynamic response over the speed controlled drive system.

The effects of adding a position control loop are more obvious in the low frequency range as the last term will bring little improvement in dynamic stiffness for the highest frequencies. This observation is very important for compliant systems which have to limit their positioning bandwidth to their lowest natural frequency.

The additional stiffness offered by the position loop can have a major impact on accuracy in the response to setpoint changes and also load influenced disturbances.

This allows systems with varying inertias (a small nip vs. a large chill roll) to accelerate much more accurately without inertia compensation or torque pre-control. Outside disturbances will also have less impact on web control.

Improved Draw Control Accuracy

The accuracy of the web tension produced from the draw control between two driven machine sections is dependent on the accuracy and stability of the speed ratio between sections, and the actual modulus of the web. Utilizing motion control for this traditionally speed coordinated function can offer a higher level of tension control through the higher precision of control of the ratio between driven sections.

With electronic gearing, the dynamic response and stability of the position controlled system ensures optimum tension control accuracy during acceleration and deceleration. The draw control ratios are position synchronous and non-drifting unlike analog drive systems and even digital speed based systems.

Virtual master setpoints can be configured in combinations of parallel or cascade, and draw changes distributed evenly and in time critical fashion. Virtual master setpoints offer noise free trajectories over traditional filtered actual values.
Improved Tension Control

Tension control can be based on the same electronic gearing concept as the draw control system. The tension loop error from the tension loop control can then be superimposed on the gear ratio as a velocity, or used to modify the gear ratio directly.

With the accuracy and stability of the electronic gear, the tension error is significantly less and requires only a small value for tension correction.

A similar configuration can be applied to a Center driven winder for improved tension control results. The configuration similar to the sectional drive tension control system with the exception that the current gear ratio is fed from the position based diameter calculator.

Figure 1: Draw Control

Figure 2: Electronic Gear based Tension Control
Position Based Diameter Calculation

For center drive winders or unwinds, the accuracy of diameter setpoint is a critical component of the winder control. Motion control allows for an improved method of diameter calculation utilizing a position length delta of the web and the angle change of the spindle.

These positions are updated at a predetermined number of spindle revolutions. Interpolation is then done between the old and new values. The benefit of this method is its ability to actually track the diameter rather that looking at individual snapshots of diameter that inevitably require filtering as in the v/n method or direct measurement sensors.

The position based calculation values used in this method are more stable and accurate than the instantaneous snapshots of speed used in the traditional v/n method. The added stability of this method can be also seen during acceleration, deceleration and at standstill. In addition, the diameter hold is not required.

Benefits:

- More accurate than the commonly used (v/n) during acceleration / deceleration / speed disturbances.
- Does not require filtering.
- Can be used with a dancer based system to also determine starting diameter.
- Diameter hold not required.

Figure 3: Position Based Diameter Calculator
Position Based Flying Splice

For unwind flying splice, the control system must sense position based inputs from the splice location on the incoming roll and fire outputs that will trigger the splice with an exact position relationship.

Traditionally this application has been solved with a PLC. The typical PLC has an operational cycle that reads its inputs, runs the program scan and calculates logic, and then sets the outputs. In many cases the program scan cycle will not be time synchronous, making the precise calculation of position with any precision very difficult at the highest speeds.

Unwind flying splice is a true position control application. This makes it a natural application for a motion control based system. Most motion control systems have the ability to capture position with high speed inputs in the background, outside of the machine control program. PLS or cam outputs can be fired in the same time sensitive manner. Additionally, program calculations can be done in time synchronous tasks. To summarize;

Position based splice features:
- Deterministic process (synchronous tasks)
- High speed and high resolution inputs (high speed position capture and cam outputs)

Position based splice results:
- Higher machine speeds
- Smaller and more precise splice overlap.

Integration of Motion Functionality with Web Control

Integrating motion control converting applications with the main drive control system can be key in the effort to improving productivity. Converting lines have utilized individual motion controlled sections, (for example; rotary knives, flying saws, metered winders) but they existed in their respective systems as stand-alone controllers. Current motion control technology can be implemented with a centralized motion based drive platform. The motion component of the drive control can reside in the same control environment as the web based drives. With a common platform, product information, and other data can be more easily shared, or production data recorded and saved via the same system that manages the web controlled drives, along with connectivity to plant MES system.

Identification of Web Modulus of Elasticity

An additional option that can be derived from the position information of a motion controlled web based drives is the identification of web modulus of elasticity. By considering the actual tension over a web position delta, the instantaneous web modulus of elasticity could be identified.

Potential uses:
- Display or process feedback.
- Dynamically change the gains of the drive tension loops.
Examples of Motion Based System Implementation

Machine Control Example #1

A major European OEM of coating / laminating machinery has standardized on a drive control concept that utilizes a single central motion controller, implementing electronic gearing on all of the driven web axes on their converting lines. The control concept included the implementation of groups of virtual references (masters) as drive section setpoints. Coat to register was changed from a speed averaging system to a position based individual product correction.

The concept change has realized the following improvements in performance and benefits over lines that had been only speed coordinated;

- Line Speed Accel/Decel rates were easily increased from 30 seconds to 15 seconds as sections with significantly different inertias could accelerate at the same rates without extensive speed and current loop tuning and the implementation of torque feedforward.
- A noticeable improvement of the drive system stability and the dynamic response of axes.
- Overall tension control improvements in the range of ~20%, without changing machine hardware.
- Improved tension control results in draw controlled sections.
- Improvement in the accuracy of registration control in coat to register (position correction vs. speed change.)
- Improved splicing and tail control accuracy of 20 times previous PLC time based systems on turret unwinds with position based splice control with a higher web speed.

Figure 4: Coating Line Drive Control Architecture
Machine Control Example #2

Tissue converting lines are a good example of where sectional drives and motion control have existed together for some time. The retrofit of a tissue converting line had the specific goal of eliminating the three different drive control platforms that caused performance and maintenance issues. The original machine design incorporated several drive control systems, one control system for the web axes, a different motion controller for the printer section and a “black box” controller for the tissue rewind section.

Following the retrofit the system control was simplified with a central drive / motion control platform that now manages all of the converting line’s drives including the printer section and tissue rewind. Electronic gearing was used for all draw control and tension web related driven axes.

In addition to the drive system unification and enhancement the following performance improvements we realized:

- A noticeable improvement of the drive system stability and dynamic response of axes.
- Tension control regulation improvements in the range of ~25%, without changing any of the related tension control and sensing hardware.

Figure 5: Tissue Line Drive Control Architecture
Machine Control Example #3

The highly demanding accuracy requirements for a label die cutting line, and demands for higher production rates, prompted a narrow web machine builder to consider an integrated drive / motion control concept.

Their label die cutter operates with a fixed speed magnetic plate die cutter. Depending on the label format, the magnetic plates wrap around the roller circumference at anywhere between 300 and 360 degrees. This can result in a gap in the cutting pattern. To prevent gaps, the label web motion is operated intermittently. During each rotation of the magnetic roller, the web briefly travels in the opposite direction to the production movement at precisely the right time. At the end of the plate gap, it is resynchronized to the roller. The reversing motion is controlled with an output cam. The exact die cutting positions are recorded with sensors using registration marks on the web and transferred within a fraction of a second to the controller to correct any deviations. Dancer rollers situated before and after the die cutting station decouple the reverse motion of the web in this area from the continuous motion of the line. A die cutter positioning accuracy of ± 0.1 millimeter (0.004 inches) at a maximum web speed of more than 90 meters/minute (295 feet/minute) was the previous machine specification.

To complicate the application, the relationship of the magnetic roll and the web changes with the contact angle of the die plate. It therefore has to be recalculated for each label format change. The integrated drive / motion controller now handles this task very precisely using a simple output cam comprising both a linear and an exact sinusoidal component. It reduces the time for the online calculation to a fraction of a millisecond. The operator now has practically no waiting time for format changes.

The implementation of electronic gearing of all the web drives, unwind, rewind and draw stations have improved the machine tension control capability to the point that not only does the machine cut labels more precisely it meets the increased production rates.

- A die cutter positioning accuracy of ± 0.05 millimeters (0.002 inches) has been realized.
- Line speeds were increased over 30% higher from 90 m/min to 120m/min.
- With the integrated control and drive solution, downtime for format changes has been significantly reduced and changes can be sent via plant MES system.

Figure 6: Drive Control Architecture
Conclusions

With the continuing demands on production speeds, product quality and with the general trend of motion based control, we find that integrated drive and motion are becoming common place in the industrial landscape. We also find the concepts and benefits of motion control based solutions can be extremely attractive for new converting lines and retrofits.

References

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