Synchronized Drive Control for Web Handling Applications

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# Table of Contents

*Abstract* 3

*Introduction* 3

**Drive Control Loop Structure** 4

  - The Speed Controlled Drive: 4
  - Velocity Loop Stiffness 4
  - Position / Velocity Controlled Drive: 5
  - Position / Velocity Loop Stiffness 5

*Position Based Web Control* 6

  - System Dynamics, Stability & Disturbance Rejection 7
  - Draw Control 7
  - Tension Control 7
  - Position Based Diameter Calculation 8
  - Electronic Gearing Based Winder 8
  - Integration of Motion Functionality with Web Control 8
  - Identification of Web Modulus of Elasticity 9
  - Position Based Flying Splice 9

*Conclusions* 9

*References* 9
Abstract

Shaftless or synchronized drive control systems have revolutionized and now become the norm in the printing industry. In all of the printing sectors presses seldom are supplied with mechanical line shafts. Modern presses are 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 this 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 basic concept in the printing industry. 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 referenced with individual speed or torque control signals.

The majority of today’s AC drives and drive control systems 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 this technology becoming standard on most drives, and machine performance criteria continually increasing, what benefits can be realized by applying this technology to web transportation systems that have traditionally speed based or have only simple velocity control requirements?

Introduction

We offer that there are multiple benefits that can be realized by applying the same electronic gearing technology that has been utilized in the printing industry for many converting and web handling applications. With the major benefits as; additional stiffness, increased stability and improved dynamics.

Consider that for the printing industry to make the conversion from mechanical line shafts to the electrical equivalent, the electrical system must offer a stiffness equal to or better than the mechanical system.

What is meant by system stiffness?

Stiffness is a measure of the displacement of a body in the presence of a unity force (torque). The force (torque) produced by a drive as input to a machine actuator (motor) depends on the variation in both speed and position that that system incurs under a disturbance and on the control parameters set for that particular application.

We can consider two types of stiffness:

- Static stiffness which is calculated using material properties and mechanical construction details when the drive motor combination motor are not energized

- Dynamic stiffness which differs from the static stiffness and is calculated for the machine once the drive motor combination are activated. Dynamic stiffness is also a measure of how well a drive motor combination can regulate to a setpoint when some outside force is trying to disturb it.
Drive Control Loop Structure

Drive systems, either DC or AC will have a minimum of two control loops, the most inner regulates the motor current and the outer loop regulates speed. If so equipped the position controller would be the outer most loop.

The Speed Controlled Drive:

In a speed regulated drive system, the speed setpoint is compared to the actual velocity of the motor, that is generated from the motor encoder and a velocity error is created. The velocity error is conditioned via PI control and a setpoint for the current controller is generated. In the current control loop the current setpoint is processed through limits then passed to the current controller for an output to the motor.

The control loop structure in a velocity controlled drive is typified in figure 1.

Figure 1: Velocity Control Loop Structure

Velocity Loop Stiffness

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:

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

One can be see that by decreasing the integral time (Tn) increases the dynamic stiffness, as well as the increase of proportional gain (Kp). While large increases of Kp may not be possible due to reaching instability limits of the speed control loop, decreasing Tn from hundreds of milliseconds to a few milliseconds may rapidly lead to an increase of two orders of magnitude.
**Position / Velocity Controlled Drive:**

In the position / velocity controlled drive, the velocity and current loops are the same as the speed controlled drive system (figure 1). However, with the addition of the position control loop, the speed setpoint is generated by the output of the position control loop. The position loop receives the actual position setpoint from the motor encoder and compares this to the setpoint generated from a position trajectory setpoint from the drives motion controller.

The control loop structure in a position / velocity controlled drive is typified in figure 2.

*Figure 2: Position Control Loop Structure*

From this diagram we can visualize how electronic gearing is accomplished. A common trajectory position setpoint is sent to multiple drives in a time concise manner. All drives follow the setpoint “synchronously”.

**Position / Velocity Loop Stiffness**

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

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

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.
Position Based Web Control

1. A major coating / laminating machine OEM utilizes electronic gearing on all of the driven web axes on their converting lines. They report the following benefits over previous designed speed regulated coordinated drive systems;
   - Driven axes with significantly different inertias can accelerate at the same rates without extensive speed and current loop tuning and the implementation of torque feedforward.
   - Improved drive system stability and dynamic response of axes.
   - Benefits of implementing stable virtual references (masters) vs. filtered actual references.
   - Improved tension control accuracy.
   - Improved draw control precision and repeatability.
   - Improved registration control in coat to register with position based correction vs. continuous speed adjustment.
   - 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.

2. The retrofit of a tissue line with synchronous drive control offered similar feedback. Electronic gearing was used for all draw control and tension control axes. The addition of the position based control of the surface based tissue winder was easily integrated in the same motion control system that controlled the web transportation drives.

Figure 3: Drive Control Architecture
System Dynamics, Stability & Disturbance Rejection

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, or outside disturbances to have less impact on web control.

Draw Control

The accuracy of the web tension produced from draw control depends on two points, the accuracy and stability of the actual draw ratio and the actual modulus of the web. Position controlled draw can offer a higher precision of control of the ratio between nips.

Figure 4: Draw Control

\[
T_{12} = T_{01} + K \frac{V_2 - V_1}{V_1}
\]

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 now 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.

Tension Control
The tension control system has a similar configuration, with electronic gearing as the draw control system. The error from the tension loop control can then be super imposed on the gear ratio as a velocity.

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

*Figure 5: Tension Control*

**Position Based Diameter Calculation**

An alternative method of diameter calculation considers a position change of the web and the angle displacement of the spindle.

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.

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. Tracking or obtaining a “history” of the diameter provides increased stability of the measurements without the filtering that is sometimes required in the v/n method or direct measurement sensors. The added stability of this method can be also seen during acceleration, deceleration and at standstill. In addition the diameter hold is not required.

- More accurate than (v/n) during acceleration / deceleration / speed disturbances.
- Does not require filtration.
- Can be used to also determine starting diameter (Actual position mode).
- Diameter hold not required.

**Electronic Gearing Based Winder**

Here the system configuration is similar to the tension control system with the exception that the current gear ratio is fed from the position based diameter calculator. Enhanced further when utilized with a position control diameter calculation and improved tension control accuracy during acceleration.

**Integration of Motion Functionality with Web Control**

Consider a converting line with the final process that is a rotary knife or flying saw. In this example the motion based 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 when compared to traditional systems that incorporate stand alone control systems for these axes.

**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. Utilize modulus of elasticity changes of the web to dynamically change the gains of the drive tension loops.

**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 fires outputs that will trigger the splice with an exact position relationship to them.

Traditionally this application has been solved with the PLC. The typical PLC has 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 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.

**Conclusions**

We submit that a position based web control system may not necessarily be an appropriate concept for each and every new or existing converting line.

But with the continuing demands of production speeds, product accuracy and the trend of motion control becoming common place in the industrial landscape, we find the concepts and benefits of position control electronic gearing can be attractive for new converting lines and also retrofits.

**References**

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