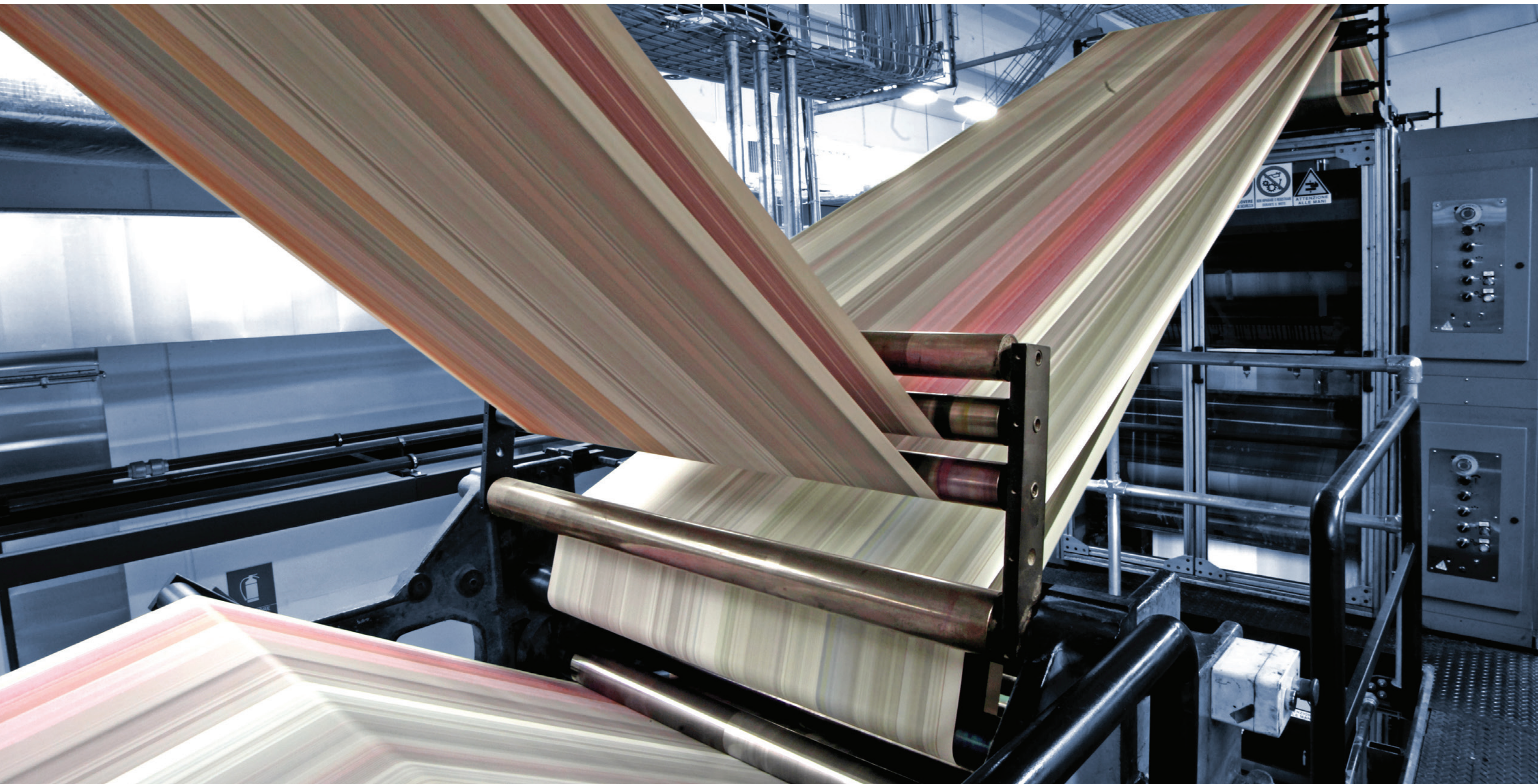
for a greener tomorrow

Four Things to Know When Designing Winder Controls



WHITE PAPER

Reduce Total Cost of Ownership

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Understanding Winding Modes for Web Handling

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Executive summary

Winding operations are the most difficult and complex of any inverter application. Consider center-wound applications, commonly used in converting lines. Rolls of industrial webs can be as large as 180 inches in diameter, unspooling to a paper core 6 inches in diameter. Typical bags for products like potato chips or dog food consist of multiple layers of plastic film laminated together. Coordinating the web tension for these layers so that they produce a smooth product is a computationally intensive task. To give an idea of just how computationally intensive, an inverter performing speed control for an average manufacturing operation would require less than 10 different parameters. For a basic winding function, speed control would likely involve over 50 parameters.

The web must maintain the appropriate tension throughout the machine. Most converting machines have multiple tension zones, in addition to a specific desired tension at the uptake roll. Tension zones can be established by nip rolls positioned on opposite sides of the web.

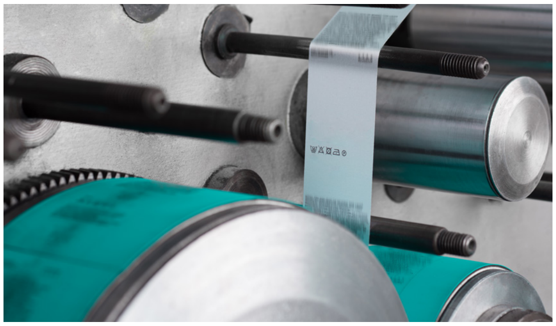
The web also needs to travel through the process steps at the desired velocity, which requires correlating roll velocity with line velocity. As the diameter of the roll increases, the angular velocity of the uptake roll must slow proportionally. This requires the drive and control system to calculate and modify the angular velocity in real time throughout the process.

Determining velocity or torque control choices

Web tension can be controlled by velocity control or torque control. In velocity control, the tension of the web at uptake is a function of roll velocity and line velocity. The uptake tension T2 is given by the following equation:

$$T2 = T1\ (V2/V1) + EA(V2 — V1/V1) \quad [1]$$

where T1 is line tension, V1 is nip roll velocity, V2 is wind roll velocity, E is elastic modulus, and A is cross-sectional area of the web.



In other words, the uptake torque is given by the ratio of the wind roll velocity to the line velocity. Velocity control is a useful approach but as the above equation shows, it scales as the elasticity and area of the web material. Velocity control works best for materials with a low elastic modulus (in other words, very stretchy or pliable). In the case of web materials with higher values of E, even a very small error in uptake roll velocity can lead to a large error in tension. For these applications, torque control is a better fit.

In torque control, the tension of the web at the uptake roll, Tu, is a function of torque and the roll diameter:

$$Tu = \tau/R \quad [2]$$

where R equals radius, and τ equals torque. Torque control is simpler, computationally speaking, as well as more accurate. It does not scale as material characteristics, so an error in torque leads to a roughly equivalent error in tension.

Key parameters for the wind/unwind operation include the diameter of the core (DC), the diameter of the roll (core plus wound material, DR), and the build-up ratio Rb= DC/DR.

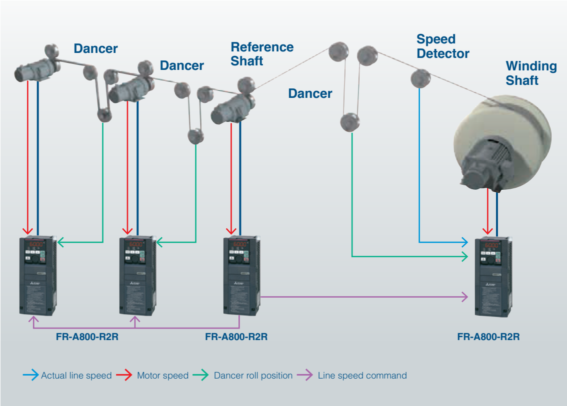
Because velocity control only involves coordinating the line velocity and roll velocity, this mode is very robust.

The four modes of winding operation

Wind/unwind modules operate in one of four different modes. Listed in order of increasing complexity, they are:

- Velocity control with a dancer
- Velocity control with a load cell
- Sensorless torque control
- Torque control with load cell feedback

Velocity control with a dancer

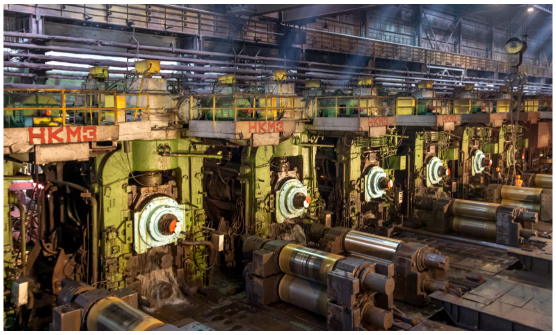


Velocity control with dancer feedback is based on closing the feedback loop. The dancer is preloaded to apply tension to the web. The position of the dancer is monitored by a sensor, typically a potentiometer, and this data is used to drive an actuator to modify web tension. The system also calculates roll diameter using uptake roll velocity, line velocity, and the gear ratio between the two. By adjusting the speed control proportional gain according to the winding diameter, the response level can be kept constant. The actual response level corrections are calculated along with the changes in the inertia ratio of the winding and unwinding shafts, improving the tracking ability to allow for the change in diameter.

Velocity control with a dancer is the most economical and user-friendly of the four winding modes. Because velocity control only involves coordinating the line velocity and roll velocity, this mode is very robust. As a result, it works well for buildup ratios as high as 20:1. On the downside, the dancer is a mechanical system, which makes it vulnerable to failure. In addition, using the potentiometer as feedback for the dancer subjects it to accelerated wear.

The method works best for fragile or very light materials that operate at low tensions.

Velocity control with a load cell



Instead of incorporating a dancer, this mode uses direct tension feedback from a load cell, applying a tension PID loop to adjust the velocity of the roll. Because the mode involves active feedback, it is more accurate than a dancer-based system. On the downside, load cells are expensive.

The load cell should be sized as close as possible to the tension needed for the web. The larger the difference between load cell and web, the lower the tension resolution. An OEM who plans to design a machine for multiple web stocks should specify or limit the products that will be used on the machine. If not, the machine will be unable to control the tension of the web.

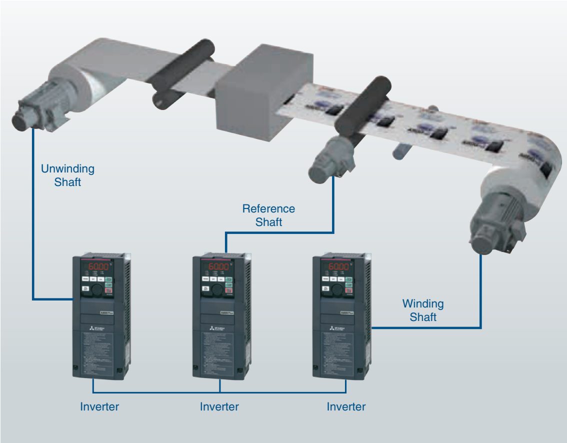
In general, load cells require greater levels of tension than dancers. As a result, velocity control with a load cell should be applied to more robust materials.

Velocity control is primarily effective for fragile or stretchy materials. For more robust materials, torque control is a better fit. Sensorless torque control mode does not involve external feedback. Instead, it calculates roll diameter using a model. It is the lowest cost velocity mode because it does not involve dancers or load cells. At the same time, it is the most complex and computationally intensive of the four. In addition to applying mechanical parameters of the roll and film, the drive must compensate for mechanical losses such as friction windage and other factors that change dynamically with the velocity, diameter, and inertia of the roll.

Sensorless torque control is best used for materials requiring medium-to-large tensions, such as steel, paper, and cardboard. Exceedingly light materials are not good fits for this mode.

The output torque of a motor is controlled to maintain constant tension on the material, by raising the commanded torque to compensate for mechanical loss caused by factors such as friction on the dancer roll or winding/ unwinding shaft.

Torque-control with load-cell feedback

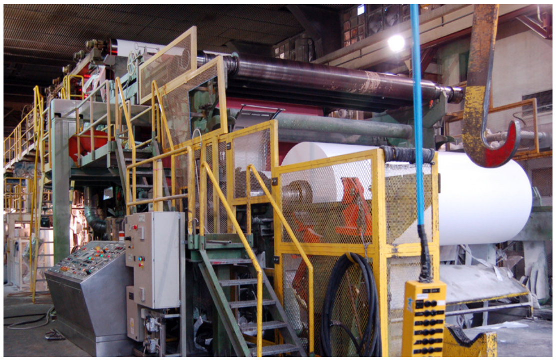


The final mode, which is torque control with load-cell feedback offers the best performance. The system is operating with two control loops. Closing the loop on torque rather than velocity means that tension error scales directly as torque. Meanwhile, the system is also operating on direct tension feedback. This is executed with a PID loop for very accurate trimming.

The output torque of a motor is controlled to maintain constant tension on the material, by raising the commanded torque to compensate for mechanical loss caused by factors such as friction on the dancer roll, or winding/unwinding of the shaft. During acceleration/deceleration, constant tension is maintained on the material by adjusting the variable tension on the winding and unwinding sides. Adjusting the tension on the material makes it possible to avoid imperfections, such as wrinkles or deformation caused by the increase in diameter. The cushion time should be set for the tension command to avoid sudden changes in roll tension. On the downside, the inclusion of the loadcell increases cost and complexity.

Selection criteria

These modes can be implemented by using a PLC or smart inverters. The PLC approach, which is based on a centralized architecture, can be challenging. Function blocks may exist for external PLCs or motion controllers, but they typically are not dedicated to winding operations. As a result, they will need custom code to address the application. This can be difficult for companies without deep engineering talent and on-staff developers.



Executing the algorithms in a smart inverter is a simpler approach, especially since inverters customized for winding are now available. Linked by field buses, particularly industrial Ethernet, smart inverters are capable of operating in master-slave mode, with one drive serving as the master controller for the system. These types of distributed architectures are particularly useful for coordinating the velocity of multiple spindles in order to maintain different tension zones throughout the machine.

Also, the networking capabilities of these drives ensures that line control and recipe management from a PLC or MES system can be downloaded to the drives for preselected parameter adjustments based on material change or order specific variations.

Implementing a successful winding stage starts with collecting the mechanical and material data for the application. What are the properties of the web? What are the properties of the roll? Don't forget to consider the mechanical components that will affect friction, as well as requirements such as line speed and duty cycle. That information should be applied along with drive information to properly size the motor. If the motor isn't strong enough to control the inertia of the roll, even the best drive will not be able to maintain tension. Finally, review the four operating modes to choose the most appropriate one for your conditions.

Manufacturing today is about performance, productivity, and profitability.

Manufacturing today is about performance, productivity, and profitability. Although motion control via servo motors can be used for winding applications, they are not always necessary nor appropriately sized. A properly sized motor teamed with a smart inverter operating in the correct mode can deliver solid performance with lower total cost of ownership.

The FR-A800 R2R family of inverters include:

- Dancer-control function using PID control
- Wind-roll diameter compensation function to speed set up
- Inertia compensation and mechanical-loss compensation to optimize tension control
- Automatic PI-based tuning function for dancer control to minimize system startup time
- Proportional gain compensation function for velocity control

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