Welcome to the winder physics training module for the DCS800, ABB DC drives.
If you need help navigating this module, please click the Help button in the top right-hand corner.
To view the presenter notes as text, please click the Notes button in the bottom right corner.
After completing this module, you will know what winding means and understand the physics of a winder. You will also know important terms of winders and be able to distinguish between the control concepts.
Basically winders are used to regulate the surface tension or force of a roll with material. The material has to be wound with a constant tension. With the thinnest webs the tension force must be reduced with increasing diameter. An optimal tension force with no or only low tension oscillations and a good mechanical leading of the web are responsible for a good rewound roll. Air inclusions between the wound web also cause problems.
Let's start with the winder basics. Winding means to unwind or rewind material, for example on a core. The core is in the middle of the roll and clamped on each side. The motor is directly coupled to the core or to a gear box. This type of winder is called a center-driven web winder which can wind aluminum, paper or film. It is also possible to wind strips. The lead rolls are an important part of the configuration. They are needed to control the line speed so that a force builds up between the roll and lead rolls. The force which is transferred to the material is called tension. Other parts of a winder are the pulleys, which guide the material on the right way.
There are several types of winders. The first type is the "center driven winder", also called the "axial winder". In this configuration the material is wound around a core which is driven by a motor. The other type is the "surface driven winder". In this type there is a difference between a roll with a shaft and a roll without a shaft. In both systems the motor affects the surface of the material, so the motor speed is constant during the complete winding process.
Important parts of a winder are in short the motor, the gear box and the roll with the core. Using a four quadrant drive allows winding in two directions, rewind and unwind. For the winding process the line speed or velocity is very important. The control performance must be high, because fast processes with high accuracy are needed. The diameter is one of the internal parameters which is used to calculate the other signals. So the accuracy of the winder depends mostly on the diameter. Further parameters include the gear ratio which defines the maximum line speed together with the motor speed. With DC motors it is easier to get greater motor speeds when using field weakening.
You have learned that the diameter is one of the important parameters for winding. There are 2
typical concepts to get the actual diameter of the roll. The most exact method is to measure the
diameter directly. This is possible with ultrasonic for example. But in most applications this
approach is too expensive and it is normal to calculate the diameter with existing values.
Calculations can be carried out with the actual motor speed and actual line speed. In reality this
calculation is done with percentage values. So it is possible to calculate with 16 bit numbers
without commas.

**Diameter calculation**

- **Possibilities to get the actual diameter**
  - Measure e.g. with ultrasonic
  - Calculate with existing actual values
    - Actual motor speed
    - Actual line speed

- **Calculation:**
  \[ D = \frac{V}{n \cdot \pi} \]

- **Using relative values:**
  \[ D = \frac{V(\%)}{n(\%)} \]
For highly accurate processes it is necessary to have a constant force on the material. This is also called tension. Constant tension depends on motor torque. This means it is important to adapt the torque reference to the actual diameter. But the torque needed for constant tension is only for processes which work constantly. During acceleration an additional torque is created which depends on inertia. The inertia of the motor, the gear box and the core is fixed but the inertia of the roll depends on the actual diameter. Another additional torque balances the losses of inertia.
The acceleration torque appears only during acceleration and deceleration of the process. It is necessary to observe the gear ratio for the inertia on the other side of the gear box, therefore all inertia must be based on the motor side. If the diameter slowly increases, the simplified equation to calculate the acceleration torque can be used. Then the change in line speed to the change in time is constant.
Another additional torque occurs because of the coupled mechanic. These losses to the mechanic are non-linear and depend on the motor speed. In practice the motor torque can be measured with several motor speeds and saved in x-y coordinates as supporting points. Then the actual motor speed is measured and the torque is an interpolation between two supporting points.
The total torque reference exists from the torque of tension, the acceleration torque and the torque from losses. The acceleration torque calculated in physical units is a very complex formula. You can see it depends on the material weight \(b\) and the density \(\rho\). We conclude that the material properties are important parameters for winding.
The power of the winding process is constant because the tension and the line speed are also constant values. So the motor power has to be dimensioned for the winding power. Do not forget the losses if they are significant. During acceleration the motor is overloaded. But this only lasts for a short time and the drive should be dimensioned for this. The motor torque is inversely proportional to the motor speed. So the characteristic curve looks like the graph.
The calculation of the windings on the roll is only applicable for material which is relatively thick. Materials in micrometer values cannot be used to calculate the windings. The equation is an approximation but the results are accurate enough for most applications.
The next topic is the control technique for winders. We can choose between tension and position controls. Tension control works with a torque reference in torque control mode. The line speed is controlled externally by the lead rolls.

The other possibility is the position control. This winder works in speed control mode with a position controller to balance the inaccuracies. In this control structure the tension is given by the force of the dancer roll. Note: Only 50% of the force created by the dancer roll affects the winding material.
To control the winder we use a typical cascade control with an inner current loop. For outer loops there are several control strategies so it depends on the winder type used. For example, it can be a speed, a position or a tension controller.
The easiest winder control concept is the speed control. In the graphic you see two rolls. The idea is to wind from one roll to another. Between the rolls for example there can be a cutter. The tension in this concept is given by a mechanical brake which is controlled by a PLC. A sensor, which measures the line speed, is important for this control strategy because there are no lead rolls to give this signal.
A better option is a dancer control because the accuracy is much higher. The winder control works in speed control mode with a position controller which balances inaccuracies. A dancer is a roll which swings up and down. The normal position of the dancer is in the middle. If the dancer moves up, the actual speed of the roll is too fast and this information is transferred to the position controller. It decreases the output value and the speed reference decreases as well.
One of the easiest and most preferred solutions is the indirect torque control. The reason is that no additional sensors are needed. The torque is not measured, so no feedback signal is necessary. Therefore the torque reference must be exactly calculated otherwise the tension is not constant and the accuracy is not precise enough.
Higher accuracy is possible with a load cell which measures the tension and provides feedback to the tension controller. The problem with this circuit is that it oscillates very fast and a PID-control is needed to get a stable configuration.
The graphic shows the typical curves of an unwinder. The pink curve is the line speed. You can see that it is initially zero and increases to normal line speed. This phase is the acceleration phase. The tension, which should be constant, is shown in black. The radius decreases from maximum to minimum as is visible in the graphic. For an unwinder it is typical that the radius decreases slowly at first. The acceleration torque is very important. You can see that during the run-up the acceleration torque reaches the maximum. If the plant works with normal line speed the acceleration torque is minimum or zero.
A rewinder is exactly the opposite. The acceleration process of the plant is identical in that the line speed increases to the normal value. The radius increases from minimum to maximum like shown on the brown curve. In the graphic you can see also that the tension is constant. This is not easy to do during the start-up phase. Only if the acceleration torque is precisely calculated you will have a chance to get good results.
Last but not least is a dancer explanation. A dancer is a swinging roll which moves up and down. It is used to balance inaccuracies. In dancer control applications the tension depends on the dancer force. Therefore it is necessary to apply force to the dancer roll, for example with a pneumatic cylinder. Note that the force for the dancer must be doubled to get the necessary tension.
There are fundamental things to know when working with winders. Normally the plant should be highly accurate for the process. This is possible with constant tension. If you wind film for example, the tension is not constant because there must be a reduction with the increase of the diameter. The line speed is an important parameter for the stability of the control circuit. A high line speed makes the circuit stable. It is important that the configuration is free of oscillation. So the control technique is a very important part of a winder.
Here are the key points of this module. Now the student should know the physics of winding and know important parts of a winder. Also knowing how to distinguish between several control concepts is important when working with winders.
Additional information

- Winder function block description
- Winder application description
Glossary

- **Dancer roll**
  swinging roll for balancing

- **Lead rolls**
  rolls to control the line speed

- **Load cell**
  roll to measure the tension

- **Core**
  metal shaft in the middle of the roll

- **Unwinder**
  winding up

- **Rewinder**
  winding

- **Acceleration torque**
  motor torque to accelerate the plant

- **Torque losses**
  speed dependent losses cause of coupled mechanic (non linear)
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