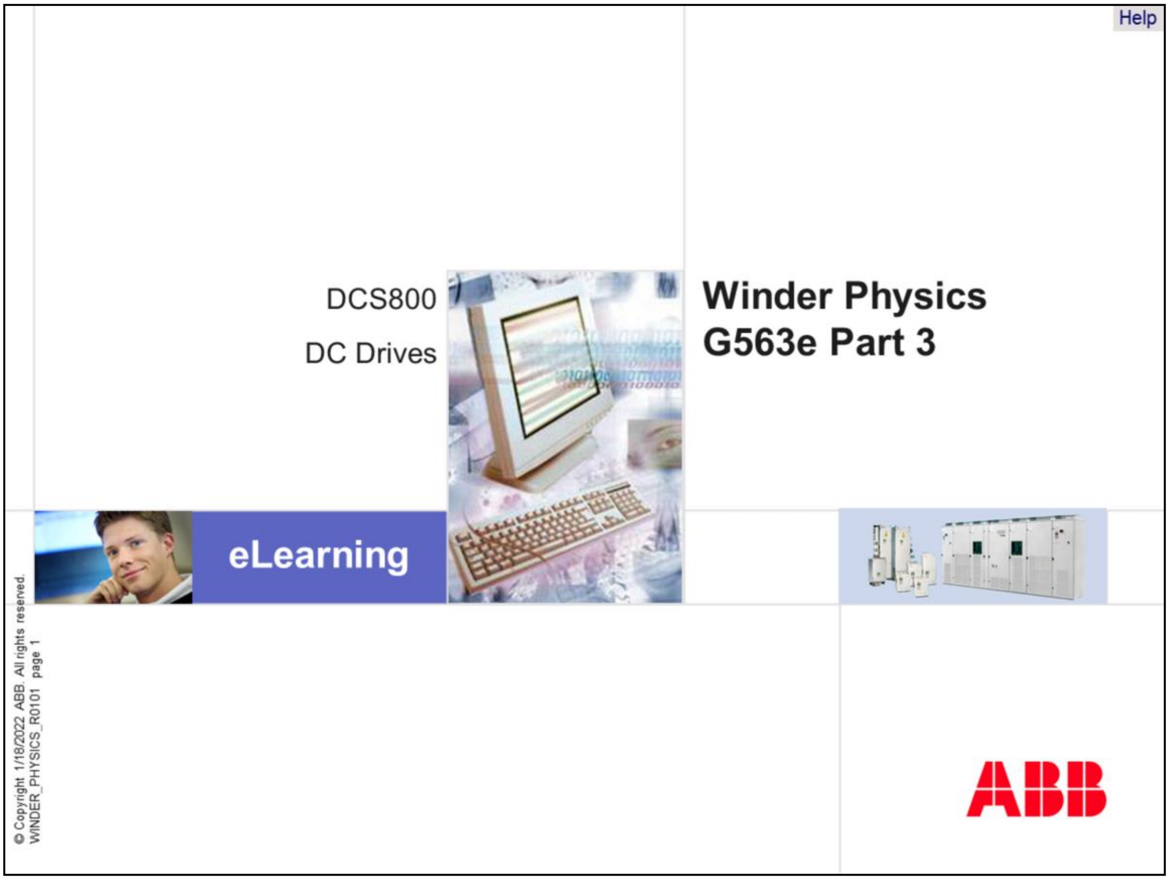


Welcome to the winder physics training module for the DCS800, ABB DC drives.

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.

Help

Objectives

After completing this module, you will be able to

- Know what "winding" means
- Understand winder physic
- Know important terms of winders
- Distinguish between control concepts

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.

Help

Winder Introduction

- A winder is used to regulate surface tension 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.
- 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.

ABB

Basically winders are used to regulate the surface tension or force of a roll with material.

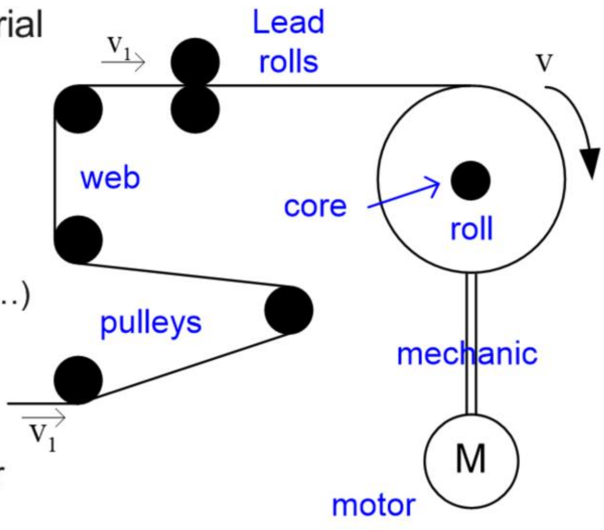
The material has to be wound with a constant tension or force. With the thinnest webs, the tension force must be reduced with increasing diameter.

An optimal tension force without any oscillations and a good mechanical leading of the web are responsible for a good rewound roll. Air inclusions between the wound web will also cause problems.

Help

What does “winding” mean?

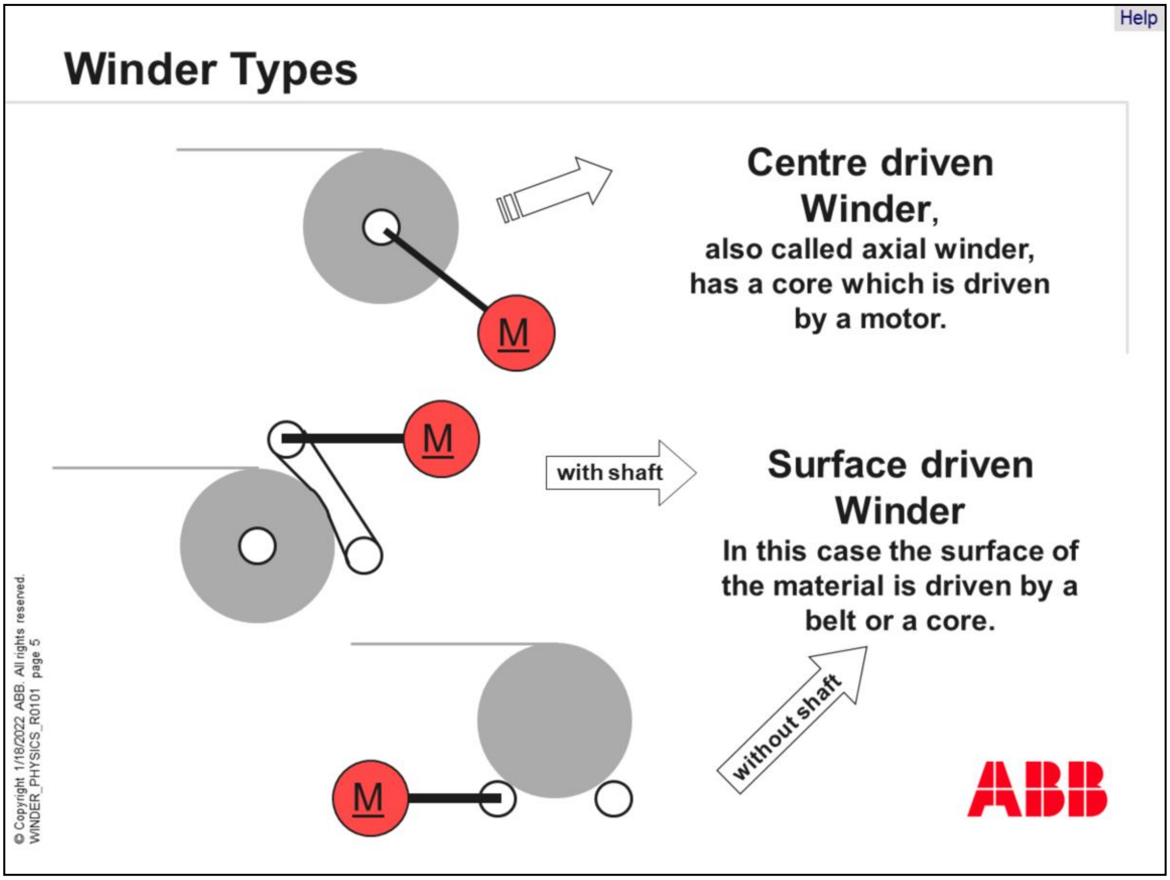
- Unwind or rewind material on a core
- Materials
  - Web (aluminum, paper, film, …)
  - Strip (steel, aluminum, …)
- Important components
  - Roll with core
  - Mechanic with the motor
  - Lead rolls
  - Pulleys
  - Material properties



WINDER_PHYSICS_R0101 page 4

ABB

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.



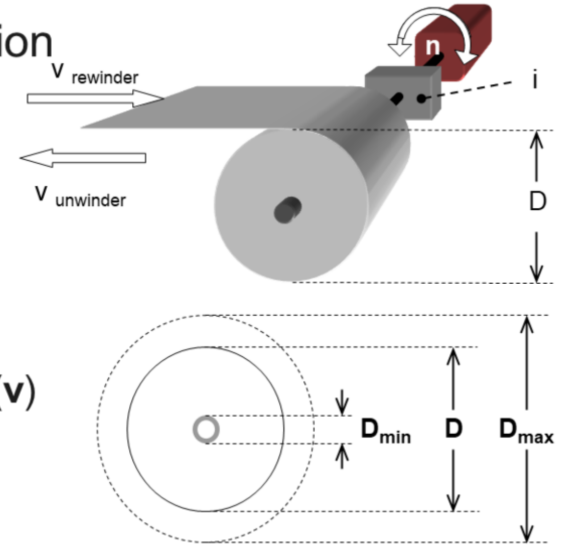
There are several types of winders. The first type is the "center driven winder", also called the "axial winder". In this configuration the material is wound around a core which is driven by a motor.

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.

Help

Winder physics I

- Mechanical construction
  - Motor
  - Gear box
  - Center core with roll
- Physical quantities
  - Line speed / velocity (**v**)
  - Diameter (**D**)
  - Gear ratio (**i**)
  - Motor speed (**n**)



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.

Help

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: $$D = \frac{v(\%)}{n(\%)}$$

ABB

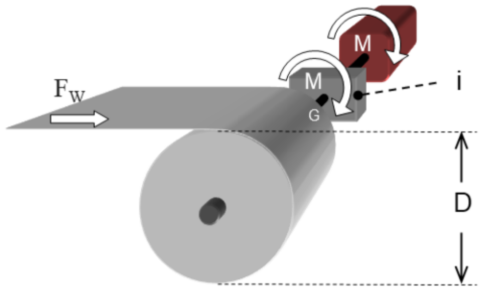
You have learned that the diameter is one of the important parameters for winding. There are 2 typical concepts to get the actual diameter of the roll. The most exact method is to measure the diameter directly. This is possible with ultrasonic for example. But in most applications this approach is too 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.

Help

Winder physics II

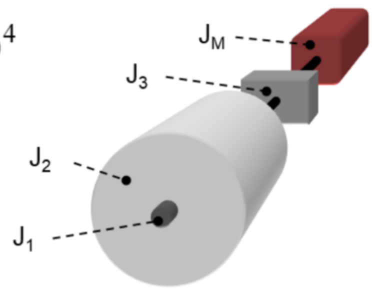
- Torque and force
  - Tension **F** must be constant
  - Torque $\mathbf{T_W}$ adapted

$$T_W = \frac{F_W \cdot D}{2 \cdot i}$$



- Winder inertia
  - Fixed: $\mathbf{J_M}$, $\mathbf{J_3}$, $\mathbf{J_1}$
  - Diameter depending: $\mathbf{J_2}$

$$J_2 \sim D^4$$



- Torque and inertia have to be converted to motor side!
- Total torque:

$$T_t = T_W + T_{acc} + T_L$$

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.

Help

Acceleration torque

- Is used to accelerate and decelerate the roll
- It depends on the diameter

$$\omega = 2 \cdot \pi \cdot n \qquad J = J_M + \frac{J_1 + J_2 + J_3}{i^2}$$

Simplified:

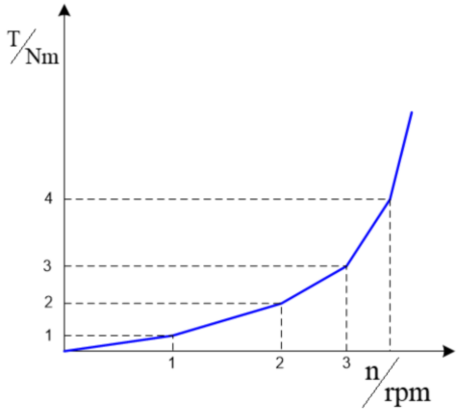
$$T_{acc} = J \cdot \frac{d\omega_{Motor}}{dt} \qquad T_{acc} = J \cdot \frac{2 \cdot i}{D} \cdot \frac{dv}{dt}$$

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.

Loss compensation

- Mechanic causes non linear losses
- Speed dependent losses:

$$T_L = T(n)$$



- Measure losses with coupled mechanic
- Save values in supporting points

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.

Help

Total torque

- Formula to calculate motor torque
  - Torque depending on tension T_W
  - Acceleration torque T_{acc}
  - Torque depending on losses T_L

$$T = \frac{F_W \cdot D}{2 \cdot i} + \left(J_M + \frac{J_1 + J_2 + J_3}{i^2} + \frac{b \cdot \rho \cdot \pi}{32} \cdot \frac{D^4 - D_{min}{}^4}{i^2} \right) \cdot \frac{2 \cdot i}{D} \cdot \frac{dv}{dt} + T(n)$$

- Internal calculated
  - Torque in percent (%)

$$T_t(\%) = T_W(\%) + T_{acc}(\%) + T_L(\%)$$

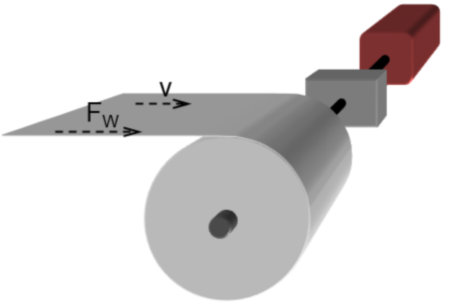
The total torque reference exists from the torque of tension, the acceleration torque and the torque from losses. The acceleration torque calculated in physical units is a very complex formula. You can see it depends on the material weight (b) and the density (rho). We conclude that the material properties are important parameters for winding.

Help

Winder physics III

- Motor power
  - Winding power:

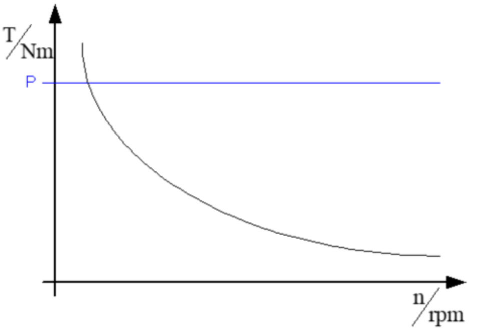
$$P = F_W \cdot v$$



- Overload must be allowed!
- Winding characteristic
  - Torque:

$$T = c \cdot \frac{1}{n}$$

$$P = const.$$



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.

Help

Calculation of windings

- Only accurate with thick material
- Actual diameter is needed
- Accuracy depends on the diameter precision

$$N = \frac{\frac{D}{2} - \frac{D_{min}}{2}}{\delta}$$

Approximation equation

δ : thickness

N : windings

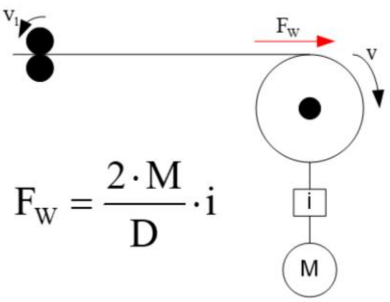
The calculation of the windings on the roll is only applicable for material which is relatively thick. Materials in micrometer values cannot be used to calculate the windings. The equation is an approximation but the results are accurate enough for most applications.

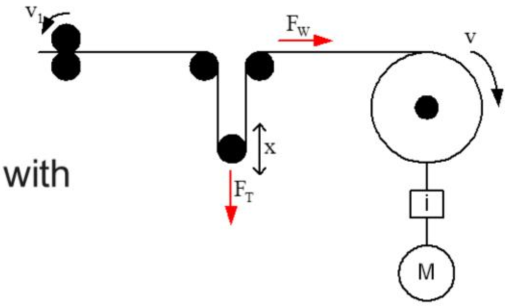
Help

Control technique for winder

- Tension control
  - Direct control of tension
  - Tension is generated from motor torque
  - Line speed is controlled from lead rolls

$$F_W = \frac{2 \cdot M}{D} \cdot i$$





- Position control
  - Indirect control of tension with a position control loop

$$F_W = \frac{F_T}{2}$$

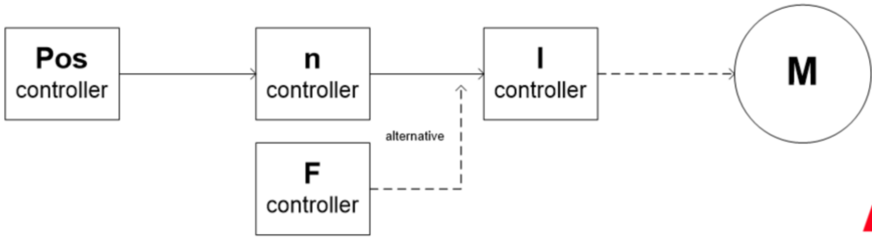
The next topic is the control technique for winders. We can choose between tension and position controls. Tension control works with a torque reference in torque control mode. The line speed is controlled externally by the lead rolls.

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.

Help

Control structure

- Cascade control
  - Inner current loop
- Further controllers depending on the regulation scheme:
  - Speed / line speed controller
  - Position controller
  - Tension controller



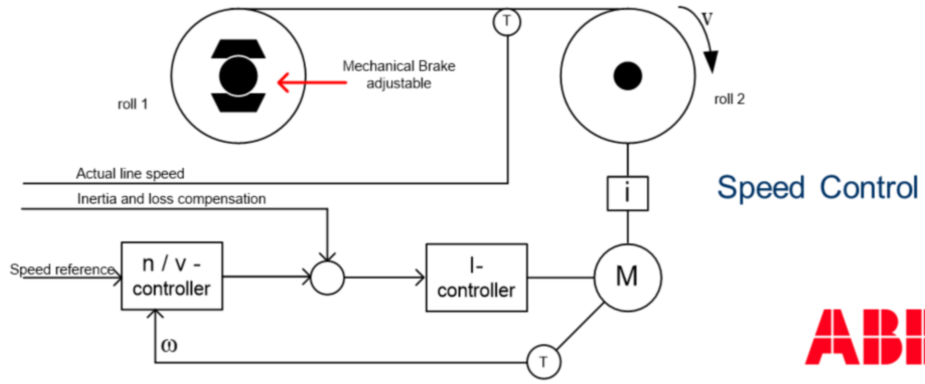
ABB

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.

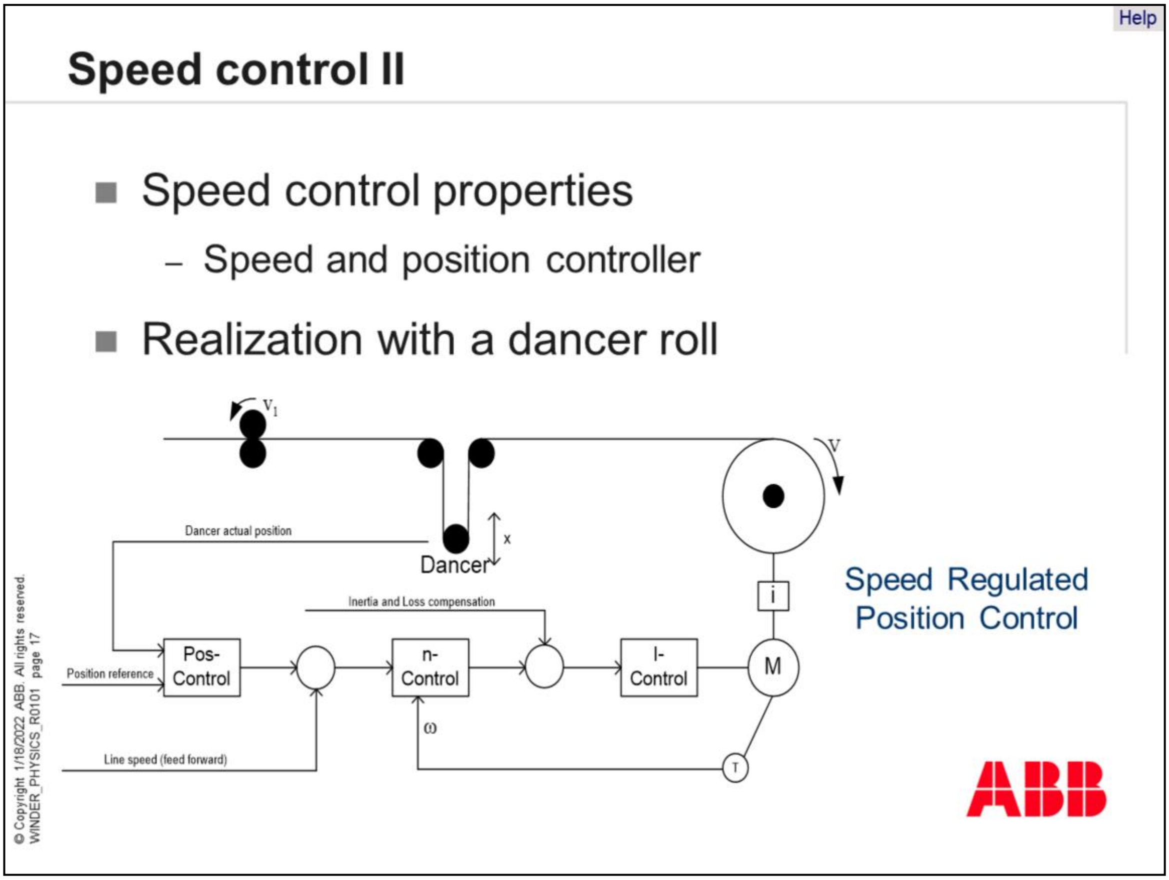
Help

Speed control I

- Speed control properties
  - Only speed control needed
- Used to wind from one roll to another
- Mechanical brake needed



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.

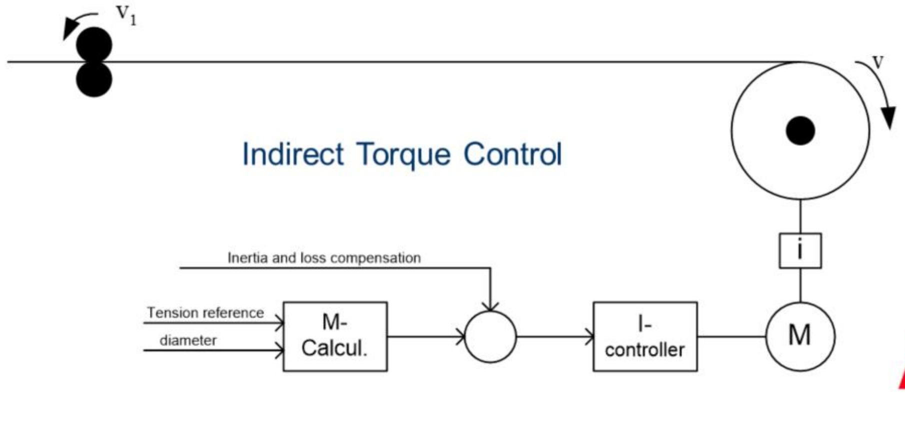


A better option is a dancer control because the accuracy is much higher. The winder control works in speed control mode with a position controller which balances inaccuracies. A dancer is a roll which swings up and down. The normal position of the dancer is in the middle. If the dancer moves up, the 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.

Help

Torque control I

- Torque control properties
  - Needed torque is calculated
- Lowest accuracy
- Most used configuration because cheap



ABB

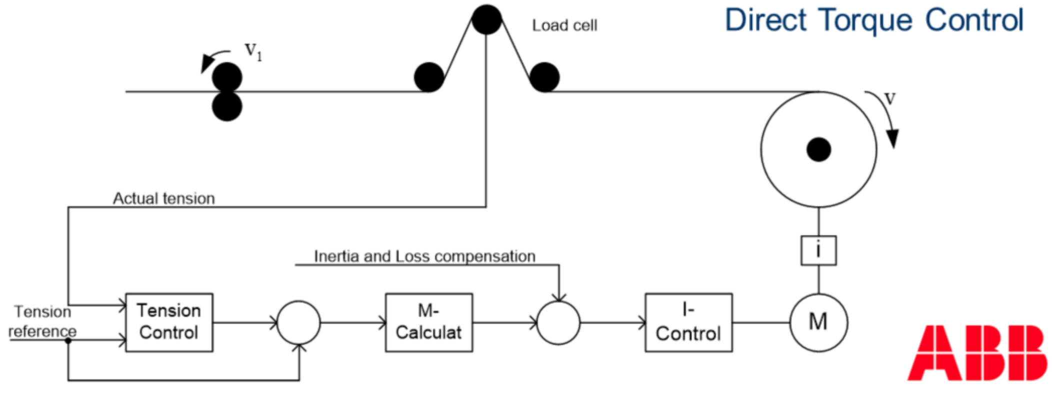
One of the easiest and most preferred solutions is the indirect torque control. The reason is that no additional sensors are needed. The torque is not measured, so no feedback signal is necessary. Therefore the torque reference must be exactly calculated otherwise the tension is not constant and the accuracy is not precise enough.

Help

Torque control II

- Torque control possibilities
  - Torque calculation
  - Tension controller
- High accuracy but complex control structure

Direct Torque Control

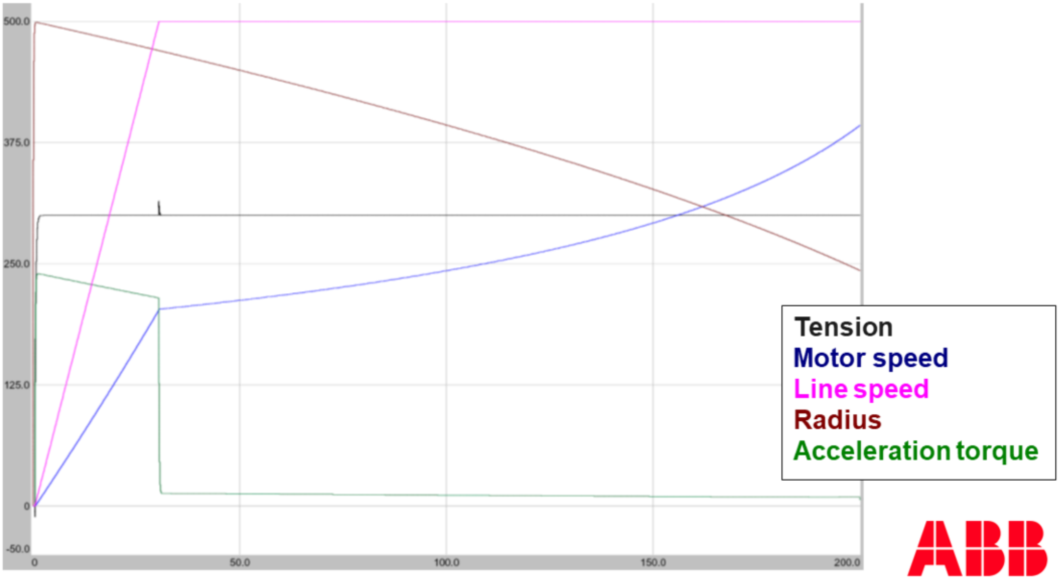


Higher accuracy is possible with a load cell which measures the tension and provides feedback to the tension controller. The problem with this circuit is that it oscillates very fast and a PID-control is needed to get a stable configuration.

Help

Typical winder curves I

- Unwinder

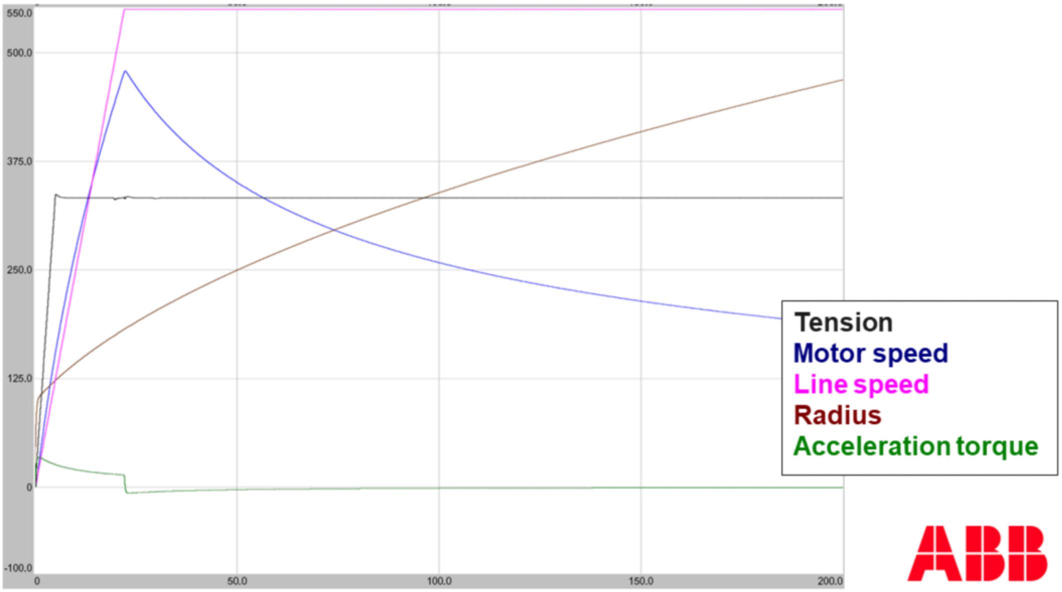


The graphic shows the typical curves of an unwinder. The pink curve is the line speed. You can see that it is initially zero and increases to normal line speed. This phase is the acceleration phase. The tension, which should be constant, is shown in black. The radius decreases from maximum to minimum 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.

Help

Typical winder curves II

- Rewinder

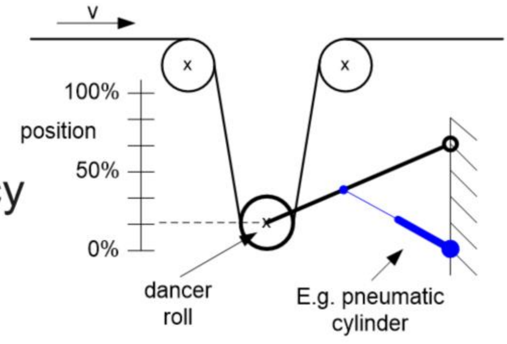


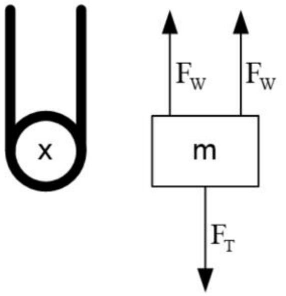
A rewinder is exactly the opposite. The acceleration process of the plant is identical in that the line speed increases to the normal value. The radius increases from minimum to maximum like shown on the brown curve. In the graphic you can see also that the tension is constant. This is not easy to do during the start-up phase. Only if the acceleration torque is precisely calculated you will have a chance to get good results.

Help

What is a dancer?

- Additional roll which is moving up and down
- Balancing of inaccuracy
- Tension depends on dancer force





Note:

Tension affect doubled!

→ Double dancer force

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.

Help

Requirements for winding

- High accuracy of the process
- Constant tension
- Constant line speed / velocity
- Free of oscillating controllers

ABB

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.

Help

Summary

Key points of this module

- Learn the physics of winding
- Know important parts of a winder
- Distinguish between winder control concepts

ABB

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.

Help

Additional information

- Winder function block description
- Winder application description

ABB

Help

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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