FACTORY AUTOMATION

ELECTROMAGNETIC CLUTCHES AND BRAKES
TENSION CONTROLLER

Tension Control Complete Guide
Tension Control Complete Guide
Chapter 1

Outline of Tension Control

1-1 What is tension control?
1-2 Places where tension control is used
1-3 Products to which tension control is applied
1-4 Tension control in manufacturing process
1-5 Let's look for tension control around you
1-6 Effect of introducing tension control
Various processing including printing, coating and slitting is applied to long materials such as paper and films by using roll-to-roll type control. To ensure stable processing, it is important to control the material tension properly and accurately.

### 1-1 What is tension control?

The unwinding tension is determined by the braking torque of the powder brake installed in the unwinding section. For keeping the tension constant, it is necessary to decrease the braking torque in accordance with the decrease of the reel diameter.

**Equipment required for tension control**

- Powder clutch
- Powder brake
- Tension detector
Chapter 1
Outline of Tension Control

1. Basis of Tension Control
2. Torque Control and Speed Control
3. Types of Tension Control
4. What Is a Tension Detector?
5. Actuator
6. System Construction
7. Application Examples
8. Trouble Examples and Corrective Actions
9. Questions and Answers

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**Main shaft motor**

The main shaft motor drives the main shaft to feed the long material from left to right. The feed speed (line speed) is determined by the motor speed, which is not related to the tension. However, a motor enabling large output is required when the tension is high.

**Winding section**

For eliminating slack of the material and generating tension, it is necessary to control the rotation speed of the winding motor. The winding speed can be adjusted correctly by vector control of the motor with the inverter.

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**Advantages of tension control**

- **Accurate**: Improving the processing accuracy
- **High speed**: Improving the time efficiency
- **No waste**: Improving the material efficiency

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Equipment required for tension control:

- Inverter and motor
- Tension detector
- Tension controller
- AC servo motor
- Inverter
- Vector control motor
- Geared motor
1-2 Places where tension control is used

- Making materials
  
  Films, paper, foils, wires and fibers

- Processing
  
  Printing
  Slitting
  Coating
  Laminating
  
  Quality control

- Inspection
1-3 Products to which tension control is applied

- Plastic shopping bag manufacturing process
Plastic shopping bags (for supermarkets) and garbage bags are manufactured by an inflatable extruder.
Heated and melted material such as polyethylene and polypropylene is extruded into a cylindrical shape by blowing air. The extruded cylindrical material is cooled, made flat when the air is discharged from the cavity, shaped into a bag-shaped sheet, and then wound.

- If the tension of the material (paper, film, etc.) is low
If the tension of the material (paper, film, etc.) is low, the material may become slack or form wrinkles during printing.
If the tension is too high, the material may shrink after printing.
If the tension is unstable, color shift may occur during printing.

Electronic device materials
Optical films
Paper and plastic
High-tech fibers
1-4  Tension control in manufacturing process

1-4-1 Example: Snack food bag manufacturing process
This section explains various industrial machines which use tension control, while focusing on the snack food bag manufacturing process as an example.

DPP (biaxially stretched polypropylene) manufacturing
DES (biaxially stretched polyethylene) manufacturing

DES vapor deposition
Laminating
Slitting

Cross sectional drawing of film
Snack food bags are manufactured using tension control technology. These bags consist of six layers including an aluminum layer to shield snack foods against ultraviolet rays, oxygen, moisture, oil, etc. (for assuring preservability and safety), and keep the flavor.

Printing on polypropylene

CPP(cast polypropylene) manufacturing

Bag making
1-4-2 Example: Lithium-ion battery production line

This section introduces an example of a process in which tension control is used in a production line for lithium-ion batteries.

**Slitting**
After the material is machined, it is cut with the slitter to fit in the battery container.

**Winding**
The positive and negative electrode materials produced in the material processing line are put in the state where they are insulated by the separator.
Products of various sizes can be manufactured by changing the material size and number of turns.

Lithium-ion batteries used for various purposes

Apply slurry (mixture paint) to the positive electrode material (aluminum foil) and the negative electrode material (copper foil).
For example:
Carbon fiber is attractive for improving fuel efficiency, improving cruising range and reducing carbon dioxide emissions. Tension control technology is also used in the production of carbon fiber and for processing molded products containing carbon fiber.

For example:
For the same purpose as with aircraft, tension control technology is used in processing molded products containing carbon fiber.
Lithium-ion battery

- For example:
  Batteries such as for mobile phones are made by laminating thin metal foils such as aluminum. Advanced tension control is required to evenly laminate thin metal foils.

Polarizing plates and protective materials

- For example:
  In liquid crystal televisions, tension control technology is used in high-function sheets for liquid crystal, film capacitors and others.

Ceramic capacitors

- For example:
  Electronic circuits are built into mobile phones, and are mounted on printed-circuit boards. Tension control technology is also used to manufacture cubic components of 1 to 2 mm called ceramic capacitors, a type of electronic component.
1-6  Effect of introducing tension control

- If tension control is not used

What happens when winding without tension control? Imagine the shape of a roll of toilet paper unwound and then rewound by hand, or the shape of a fishing reel wound without a weight. The shape will not be wound neatly!

1-6-1 Improving the wound shape

In the material processing and winding stages, satisfactory wound shape can be achieved by tension control. If tension control is not performed properly, the following problems may occur:

- Chrysanthemum pattern:
The center is crushed due to tight winding.

- Dented roll:
The center is dented after winding.

- Arc-shaped curve and bamboo shoot:
The material slips out of place during winding.

- Shoulder-missing roll:
Both sides are missed during winding.
1-6-2 Improving the printing quality

If the tension is insufficient, wrinkles form on the material surface during printing, and the printing pattern may become discontinuous.
If the tension is excessive, the material is stretched too much during printing. When the tension is lost after printing, the material may shrink and the printed pattern may be deformed.
By keeping the proper tension, neatly finished multicolor printing is achieved.
If the tension is not constant or fluctuates in each printing unit, colors may overflow or bleed, and the printed pattern may be deformed.

1-6-3 Improving the processing quality in the slitter

Tension control only in each winding reel shaft is not sufficient.
If the tension is not the same in the upper area and the lower area, the width may be uneven, and wrinkles and slackness may occur.
1-6-4 Improving the processing quality in the laminator

If the tension is not controlled properly between the upper area and the lower area, wrinkles and curls may form due to elongation and shrinkage of the material.

1-6-5 Improving the processing quality in the coater

If the tension is uneven between before coating and after coating, the material thickness may become uneven and the product quality may deteriorate.

**Point!** Why is tension control required?

The purpose of tension control varies depending on the material and machine. When the tension is controlled properly, the material can be transferred to the next process (such as printing, laminating and machining) with proper tension, which stabilizes the material travel, ensures dimensional accuracy and achieves satisfactory winding.
Chapter 2

Basis of Tension Control

2-1 What is tension?
2-2 What is torque?
2-3 Forces causing tension
Chapter 2 | Basis of Tension Control

2-1 | What is tension?

Various physical phenomena occur in machines which process long materials. However, it is difficult to link them with phenomena which occur in daily life.

- Pulling force and pulled force

When two people pull a rope against each other, tension is applied to the rope. Clearly, the pulling force \( F \) and the pulled force \( F' \) balance each other and the same tension is applied by both people while the rope is stopped.

What is the tension when the rope is moving? If one side is not fixed, the rope moves to the right. A smaller force \( f \) acts on the rope. This means that the tension is not determined by the force on the pulling side when the rope is moving. The tension is affected by the force on the pulled side.
2-2 What is torque?

The left figure shows the relationship between the tension and the torque when a long material is fed out. The term “torque” refers to the force applied to the rotary shaft. When a long material is fed out, it is fed rightward because the braking torque of the reel shaft is weaker than the motor torque.

In this case, the tension \( f \) applied to the material is determined by the braking torque \( T \) on the weaker side. The expression below shows the relationship between the torque \( T \) and the tension \( f \) at that time:

\[
Tension (f) = \frac{Torque (T)}{Radius (D/2)}
\]

2-3 Forces causing tension

Next, let’s consider an example of forces which cause tension in actual machines.

Which forces act when a long material is fed out?

The major forces are as follows:

- Tension generated by pulling: \( F \)
- Inertia moment: \( I \)
- Angular acceleration: \( \alpha \)
- Torque generated when the angular acceleration changes during acceleration/deceleration: \( I \times \alpha \)
- Friction resistance generated by friction of the shaft: \( Tn \)
- Load torque: \( Tb \) (corresponding to the braking torque)

The following equation of motion shows the rotational motion:

\[
F \times \frac{D}{2} = I \times \alpha + Tn + Tb
\]

“\( I \times \alpha \)” is generated when the angular acceleration changes during acceleration or deceleration, and has no effect when the speed is constant.

The friction resistance “\( Tn \)” is caused by friction resistance (mechanical loss) generated when the bearing which supports the shaft, gear or belt is driven.

“\( Tn \)” changes in accordance with the temperature and rotation speed. The bearing changes in accordance with the gap accuracy and seal type, and its value is not constant.

“\( Tb \)” is the load torque generated by the brake, etc.

To control the tension, it is necessary to control these three torques properly.
2-3-1 Inertia moment

The inertia moment is an index which expresses the difficulty of rotating in the rotating body. The mass in linear motion indicates the "difficulty of moving" and "difficulty of stopping" when a force is applied. The inertia moment in rotational motion indicates the "difficulty of rotating" and "difficulty of stopping" when a force to cause rotation is applied.

For example, it is difficult to start rotating a reel shaft that has a large outside diameter or large mass, but the shaft inherently continues to rotate once it starts rotating. This property is referred to as "The inertia moment is large". The expression below shows the property:

\[
\text{Inertia moment} = \sum \left( \text{Distance from center of rotation} \times \text{Mass} \right)
\]

The inertia moment is small.

The inertia moment is large.

It is necessary to consider the inertia when accelerating or decelerating a rotating body. The torque \( T \) required for accelerating a rotating body whose inertia is \( I \) is as follows:

\[
T = I \times \alpha
\]

Accordingly, it is necessary to consider that the torque appears as tension on the + side (pulling side) when accelerating the rotating body by pulling it, and appears as tension on the - side (slacking side) when decelerating the rotating body.

Torque is not generated during steady operation at a constant speed because the angular acceleration \( \alpha \) is 0.
2-3-2 Force generated by the friction resistance (mechanical loss)

When the shaft rotates, friction resistance is generated in the bearing which supports the shaft, gear, pulley, etc. The friction resistance also causes tension. Because the effect of the friction resistance cannot be ignored when controlling low tension, proper measures are required.

Point!
Let's study the basic concepts of tension, torque, inertia moment and friction resistance (mechanical loss)!
MEMO
Chapter 3

Torque Control and Speed Control

3-1 Torque control and speed control
3-2 How to use torque control and speed control properly
3-3 Examples of speed control
3-4 System design flow
3-1 Torque control and speed control

There are two main methods of tension control, the method using torque control and the method using speed control.

In torque control, only the torque required to control the tension is controlled among the three torques acting on a long material described in Section 2.3; the other torques required to control the friction resistance and inertia are controlled and corrected as necessary.

In speed control, the speed of feeding a material is controlled to stabilize the tension. The tension is applied through pressurization by the weight and dancer roll, and is determined by the course of events. Accordingly, in order to manipulate only the torque for controlling the tension during speed control, it is necessary to change the pressurization of the dancer roll or to perform draw control which utilizes the difference in the material feed speed.
3-1-1 Mechanism of torque control

The left figure shows an example of torque control during unwinding. In torque control, the effect of inertia caused by acceleration/deceleration and the friction resistance are almost constant when the material moving speed is constant. Accordingly, the tension can be controlled easily only by applying a constant braking torque.

The rotation speed of the reel shaft is determined by the course of events based on the feed speed and reel diameter (material diameter wound around the reel shaft). By adopting an actuator* which generates a constant torque even if the rotation speed changes, the intended tension can be achieved easily without considering changes in the rotation speed of the reel shaft only by changing the torque for controlling the tension.

On the other hand, if the effect of the inertia (inertia moment) during acceleration/deceleration and the mechanical friction change considerably during torque control, it is difficult to completely eliminate fluctuations of the tension caused by such changes.

As the reel diameter becomes larger, the inertia of the reel becomes larger accordingly, and the torque required to compensate the inertia increases. Accordingly, torque control becomes more difficult with larger inertia and higher acceleration/deceleration speed.

* An actuator is: Driving equipment such as clutches, brakes and motors installed in the winding reel shaft and unwinding reel shaft.
3-1-2 Mechanism of speed control

The left figure shows an example of speed control during unwinding. In actual machines, the rotation speed of the motor which feeds out the material is controlled. For applying the tension, the weight is hung on the dancer roll* as shown in the left figure or the dancer roll is pressurized by the air cylinder, etc.

In speed control, the speed of the material moving in the machine is detected, and the machine is controlled so that other driving parts of the machine synchronize with the detected speed. Accordingly, it is easy to stabilize the movement of the material.

In addition, because the torque is determined by the course of events even if the torque caused by inertia and the torque caused by mechanical friction fluctuate, the stability of the material deteriorates less. However, because it is not possible to change only the torque for controlling the tension, the tension accuracy is low. In speed control using a dancer roll, the tension is changed by the weight attached to the dancer roll or the pressurization applied to the dancer roll by the air cylinder, etc. If a weight is attached, the inertia of the dancer roll increases. As a result, the response of speed detection becomes low, and the tension may fluctuate in some cases. If the dancer roll is pressurized by the air cylinder, etc., fluctuations in the air cause fluctuations in the tension. Accordingly, the absolute control accuracy of the tension is lower than that in torque control.

* A dancer roll is: A follower roll (guide roll) whose spindle can move longitudinally or laterally. The tension of the material is determined by the load applied to the dancer roll spindle.
Dancer rolls are rollers which move considerably longitudinally or laterally, and are classified into weight dancer rolls, spring dancer rolls, etc.

- **Weight dancer roll**
  - The tension is 1/2 of the mass of the weight.
  - The dancer roll position is not related to the tension.
  - The dancer roll position depends on the difference between the input speed and the output speed.
  - The material is easily made stable even during acceleration or deceleration.
  - Synchronization is achieved easily even if the material between the driving controlled shafts is long.
  - It is necessary to change the mass of the weight in order to change the tension.

- **Spring dancer roll**
  - The spring force of the spring causes the tension.
  - The dancer roll position is changed by the tension.
  - The dancer roll position is not changed by the difference in speed.
  - The tension control accuracy is better compared with the weight dancer roll.
  - The dancer roll absorbs shock.
  - It is necessary to stabilize the spring (so a damper is required).

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Applicable equipment

- **AC servo motor**
  - MELSERVO-J4

- **Inverter**
  - FR-A800

- **Vector control motor**
  - SF-V5RU
3-2 How to use torque control and speed control properly

<table>
<thead>
<tr>
<th>Torque control</th>
<th>Speed control</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Good</strong></td>
<td><strong>Bad</strong></td>
</tr>
<tr>
<td>The accuracy is determined by the torque generated by the actuator, and detailed control is possible.</td>
<td>The tension is determined by the weight attached to the dancer roll or the pressurization by the air cylinder. It is not possible to change only the torque used for controlling the tension even if the tension changes.</td>
</tr>
<tr>
<td><strong>Bad</strong></td>
<td><strong>Good</strong></td>
</tr>
<tr>
<td>Control is difficult because it is affected by changes in the torque caused by changes in the inertia. Because the reel shaft can rotate only when it is pulled by a force overcoming the inertia of the reel shaft, the lower limit of tension is restricted.</td>
<td>Because the tension is determined by the weight attached to the dancer roll or the pressurization by the air cylinder even if acceleration or deceleration is performed, the control is less affected by acceleration or deceleration. Because the reel shaft can be driven, the tension can be made low by positively feeding out the material.</td>
</tr>
</tbody>
</table>

3-3 Examples of speed control

1. Method using the tension detector*

   [Features of speed control using the tension detector*]
   - Speed control can be performed using a simple configuration.
   - The tension accuracy is better than the method using the dancer roll.
   - The tension stability is rather low.
   - The controllability considerably changes in accordance with the characteristics of the material.

   * A tension detector is:
   Equipment which converts the tension into load once, and takes the load as the electrical signal.

2. Method using the dancer roll (Pressurization by air cylinder)

   [Features of speed control using the dancer roll]
   - The tension stability is high even with acceleration or deceleration.
   - Synchronization can be easily achieved even if the path is long.
   - The dancer roll absorbs shock.
   - The tension accuracy depends on the air pressure and machine mechanism.
Method using the dancer roll (Pressurization by powder clutch)

[Features of speed control using the powder clutch]
- The tension can be changed by the torque of the powder clutch.
- The dancer roll position depends on the difference between the input speed and the output speed.
- Synchronization can be easily achieved even if the path is long.
- The dancer roll position is not related to the tension.

Method using draw control

When many follower rolls are driven by the traveling material as shown in the left figure, the tension may become excessive toward the head area due to the effect of mechanical loss in the follower rolls.

For driving each follower roll to prevent excessive tension, it is necessary to control the speed in accordance with the elongation and shrinkage of the material.

It is possible to drive each roll using the servo motors, and to drive the servo motors in the rear area at a higher speed than the servo motors in the front area using the ratio setting units as shown in the left figure.

The elongation percentage is approximately 0.1 to 5%.

The method of driving rolls in the rear area at a higher speed in this way is called draw control. The operation tension is determined by the elongation percentage property of the material.

Applicable equipment

- AC servo motor: MELSERVO-J4
- Inverter: FR-A800
- Stationary tension detector: LX-TD
- Flange-type tension detector: LX7-F
Let’s consider the combination of control type (torque control or speed control) and auxiliary device (dancer roll or tension detector).
Chapter 4

Types of Tension Control (Torque Control)

4-1 Manual control
4-2 Open-loop control
4-3 Closed-loop control
Types of Tension Control (Torque Control)

Tension control (torque control) is classified into three types: "manual control", "open-loop control (reel diameter detection method)" and "closed-loop control (tension feedback method)".

4-1 Manual control

4-1-1 What is manual tension control?

In manual tension control, the excitation current or applied voltage of the clutch or brake is adjusted gradually in accordance with changes in the reel diameter during winding or unwinding so that almost constant tension can be obtained. Various power supply units are available in manual control including the one which automatically compensates changes in the supply voltage and the one which offers constant current even if the temperature of the excitation coil changes in the clutch or brake.

[Advantages]

- When compared with the mechanical type
  - The control stability is high.
  - Adjustment is easy.
- The initial cost of introduction is low.

[Disadvantages]

- The control accuracy is low.
- The control quality depends on the human senses.
- Only gradual control is available.

Applicable equipment

The LD-40PSU (constant-voltage type manual power supply unit) incorporating the adjustor, LE-50PAU (constant-voltage/constant-current selectable type power amplifier) to be combined with an external adjustor and LD-10PAU (constant-current control type power amplifier) are available. Among them, the power amplifiers are used also to amplify the output signal from the tension controller described later and excite the clutch or brake. Various other power supply units and parts are available.
4-1-2 Usage example of manual power supply unit

When the reel diameter ratio (Maximum diameter/Minimum diameter) is small in the processing machine for paper, film, wire, etc., for the intermediate shaft whose reel diameter does not change, or when high tension accuracy is not required, the manual power supply unit is used as shown in the left figure. Though high tension accuracy is not expected, the tension can be changed easily using the variable resistor provided on the panel of the power supply unit. In addition, because the structure is simple, the tension can be adjusted at low cost.

4-1-3 Usage example of power amplifier

When there are many controlled shafts and the PLC performs centralized control, it is recommended to use the power amplifier as shown in the left figure so that the powder brake/clutch can be used very easily.
4-1-4 Usage example of power amplifier unit (In motor inspection)

The powder brake is effective as a load of the motor load testing unit.

As an example, select a powder brake for measuring the characteristics of a motor with speed reducer whose output is 600 W (Torque: 44 Nm, rotation speed: 130 r/min) as shown in the left figure.

![Diagram of motor and power amplifier system]

The heat dissipation \( P \) is as follows:

\[
P = 0.105 \times T \times N_r = 0.105 \times 44 \times 130 = 600 \text{ (W)}
\]

(As shown in the calculation result, the motor output is equivalent to the heat dissipation of the powder brake.)

Select the powder brake ZKB-5HBN. (Allowable continuous heat dissipation: 1100 W, rated torque: 50 Nm, allowable rotation speed: 1800 r/min)

The load torque applied to the motor is changed by changing the excitation current of the powder brake using the constant-current type power amplifier, and then changes in the motor current and rotation speed are recorded. Feedback control is enabled when the signal from the torque detector is sent to the tension controller.
4-2 Open-loop control

4-2-1 What is open-loop control?

In open-loop control, the reel diameter is detected in the winding section and unwinding section, and the winding torque and unwinding braking torque are controlled based on the reel diameter.

When the tension is kept constant in open-loop control, the reel diameter and reel shaft torque are controlled proportionally. As a result, stable tension control is achieved without the sensitive effect of abrupt disturbances compared with the tension detection method (closed-loop control) described later.

Open-loop control is available also in simple taper control and control of such machines that cannot be combined with the tension detector.

However, because open-loop control is affected by torque changes and linearity of the actuator and mechanical loss, the absolute accuracy of tension is rather lower than feedback control.

[Advantages]
- The initial cost of introduction is lower than that of closed-loop control.
- Stable control is achieved.
- A tension detector is not required.
- Taper control is easy.

[Disadvantages]
- The effect of mechanical loss and actuator characteristics cannot be ignored.
- The controlled tension cannot be grasped.

Applicable equipment

Tension controller
LE7-40GU-L + LE7-DCA
(Reel diameter calculation option)

Open-loop tension controller
LD-30FTA

Open-loop tension controller
LD-10WTB-CCL
4-2-2 Reel diameter detection and calculation method

- **Method to detect the reel diameter by touching the material**
  - Touch arm (lever) method

- **Method to detect the reel diameter without touching the material**
  - Ultrasonic method

- **Method to calculate the reel diameter without touching the material**
  - Integrated thickness detection method
  - Speed & thickness setting method
  - Ratio calculation method

**● Touch arm (lever) method**

In this method, the moving angle of the roll in contact with the reel diameter is detected by the motion of the lever, and a signal in proportion to the reel diameter is obtained.

- The potentiometer, differential transformer, etc. are available as arm angle detection sensors.
- Care is required so that the material surface is not damaged by the contact.
- It is necessary to adjust the pressing pressure of the arm.

**● Ultrasonic method**

In this method, the signal returned by reflection is read by the ultrasonic sensor, and then the reel diameter is obtained.

- The material is not damaged because contact is not required.
- Some materials cannot be detected by the ultrasonic sensor.
- The reel diameter increase/decrease direction does not agree with the voltage change direction.

**● Integrated thickness detection method**

In this method, the reel diameter is calculated from the reel shaft rotation speed detected by the proximity switch attached to the reel shaft, reel shaft initial value and material thickness.

In this method, the current reel diameter is obtained by calculating the accumulated material thickness with reference to the reel diameter initial value by utilizing the fact that the reel diameter changes by twice the material thickness per rotation of the reel shaft.

- The noncontact type reel diameter calculation can be performed easily only by installing one proximity sensor.
- Errors may be generated due to elongation of the material and involvement of the air.
- When the material is thick, the pulse number per rotation can be increased.
Speed & thickness setting method (Sensorless method)

In this method, the reel diameter changing in accordance with the lapse of time is calculated from the material thickness set value and average speed value.

The left expression shows the reel diameter \( D (\text{mm}) \) when the material having the thickness \( T (\mu\text{m}) \) is wound and unwound at the line speed \( V (\text{m/min}) \).

When the minimum diameter \( D_1 \) (for winding) or maximum diameter \( D_4 \) (for unwinding) is set as the initial value and the material thickness \( T \) and average speed \( V \) are set, the change in reel diameter \( D \) with lapse of time can be automatically calculated using the left expression.

This method is called "speed & thickness setting method".

Ratio calculation method

In this method, two sensors, the proximity switch attached to the reel shaft and the rotary encoder detecting the rotation speed of the feed roll, are used.

In this method, the reel diameter is calculated by counting the pulse number of the rotary encoder per rotation of the reel shaft by utilizing the fact that the rotation cycle of the reel increases as the reel diameter increases and the pulse number of the rotary encoder installed in the feed roll having a constant diameter does not change provided the speed is constant.

Because errors caused by changes in the material thickness due to elongation of the material and involvement of the air are not generated, the reel diameter can be calculated with higher accuracy compared with the integrated thickness monitoring method provided slip does not occur between the feed roll and the material.

- The reel diameter can be calculated with high accuracy.
- The resolution of the reel diameter calculation is determined by the pulse number of the encoder.
- Accurate calculation of the reel diameter is possible only after the reel shaft rotates twice.
In the closed-loop control method, which is also called the tension feedback method, the material tension is directly monitored by the tension detector, and the monitored value is fed back so that the monitored value becomes equivalent to the tension control target value.

Though accurate tension equivalent to the target value is obtained, the phenomenon of “hunting” easily occurs due to short-time disturbances. To cope with this, proportional integral control is generally performed.

Because the tension is fed back, the tension accuracy is better than that of open loop control.

### Advantages

- The control accuracy is high.
- The controlled tension can be read directly.
- The torque characteristics of the actuator are also corrected.

### Disadvantages

- The control is susceptible to short-time disturbances.
- The initial cost of introduction is large.
- It is necessary to coordinate the machine manipulation and control.

**Applicable equipment**

- Tension controller
  - LE7-40GU-L
- Closed-loop tension controller
  - LE-10WTA-CCL
Classification of tension control methods

The tension control methods of powder clutches/brakes are mainly classified into the following three types:

- Manual control: The material tension is adjusted by human senses.
- Open-loop control: Controlled torque in proportion to the reel diameter is generated.
- Closed-loop control: The tension is detected by the sensor, and then controlled so that it matches the target value.
Chapter 5

What Is a Tension Detector?

5-1 What is a tension detector?
5-2 Types and features of tension detectors
5-3 Selection of tension detectors
5-4 Tension and load
5-5 Cautions on attaching the tension detector
5-1 What is a tension detector?

A tension detector is a device which converts tension into load once, and uses the load as an electrical signal. A detection roller is installed above the tension detector and guide rollers are installed before and after the tension detector, and the material passes through each roller. By this setup, the tension applied to the material is applied as load on the tension detector via the detection roller.

The internal flat spring bends in accordance with the load applied to the tension detector, and the load is output as an electrical signal by the differential transformer.
5-2 Types and features of tension detectors

- **Differential transformer type**

  The LX-TD and LX7-F tension detectors manufactured by Mitsubishi Electric Corporation use a differential transformer.

  ![Diagram of tension detector][1]

  **[Features of differential transformer type]**

  - The sensor section does not contact the detection target, and is highly resistant to shock.
  - Because the output voltage is high, this type of sensor is highly resistant to electrical shock compared with other types of sensors.
  - Fewer errors are generated during amplification.
  - Correction is required against temperature changes.

- **Other types**

  - **Strain gauge type**
    - The structure is simple because the sensor can be directly pasted to the spring.
    - The output voltage is small.
    - Correction is required against temperature changes.
    - This type is susceptible to humidity.

  - **Pressductor®**
    - The load can be detected even if the displacement is small.
    - This product is suitable for high tension.
    - The amplifier circuit is complicated.
    - The price is high.

  - **Magnetostriction type**
    - The sensor section does not contact the detection target, and is highly resistant to shock.
    - Correction is required against temperature changes.
    - The response speed is slow.
    - The amplifier circuit is complicated.
5-3 Selection of tension detectors

5-3-1 How to select a tension detector

The following conditions should be examined in order to select a proper tension detector:
- Tension detector types
  - Stationary type
  - Flange type
- Range of tension usage
- Weight of the tension detection roller
- Tension detector attachment angle
- Input/output material angle
- Center height of the pillow block (Stationary type only)

Load caused by the material angle and tension

Figure (1) shows that the load applied to the tension detector differs with a change of material angle even if the tension is the same. Because the load applied to the tension detector varies depending on several conditions including the material angle even if the tension is the same, it is necessary to select a proper tension detector in accordance with the existing conditions.

The loads applied to the tension detector can be classified into the following two types as shown in Figure (2):
- Load caused by the tension detection roller: Roller load
- Load caused by the tension: Tension load

A proper tension detector can be selected by calculating the above two loads.

Load caused by the tension detection roller

Because the tension detector detects the load around the supporting point as described above, the roller load detected by the tension detector differs with a change of tension detector attachment angle as shown in Figure (3).
Effect of the center height (Stationary type)

A pillow block (bearing) is used to connect the tension detector and tension detection roller as shown in Figure (4). The height of the pillow block (bearing) is called the "center height". The tension load detectable by the tension detector varies depending on the center height.

When the center height changes, the distance between the "supporting point of the tension detector" and the "center of the tension detection roller" changes accordingly.

In the same way as the principle of leverage, the tension load detectable by the tension detector changes even if the tension is the same.
5-4 Tension and load

5-4-1 Load direction and detection direction

Figure (1) shows the relationship between the tension and the load applied to the tension detector. The tension detector uses the center of the hinge spring as the supporting point, and detects the load in the rotation direction whose center is the supporting point. Because the amount of deflection of the base is extremely small, the load detection direction can be effectively regarded as perpendicular to the tension detector.

When the tension is applied as shown in Figure (2), the load is applied in the arrow direction due to the tension. However, the tension detector actually detects only the force in the vertical direction as the load, and does not detect the force in the horizontal direction.

As described above, loads applied to the tension detector can be classified into “detected force” and “undetected force”.

Load direction and detection direction

The tension is applied in two directions, on the input side and on the output side, as shown in Figure (3) and Figure (4). The sum of both forces is applied as the load on the tension detector.

When two tension detectors are used as shown in Figure (3) and Figure (4), the applied load is "(Load caused by tension on input side + Load caused by tension on output side)/2".
5-5 Cautions on attaching the tension detector

5-5-1 How to attach the tension detector (Stationary type)

Because the tension detector is highly sensitive equipment manufactured by precise processing and assembly, care is required when attaching it.

(1) Attachment using the standard pillow block

The pillow block and pillow block mounting bolts are not provided as standard accessories. Make sure that the length of the pillow block mounting bolts does not exceed the thickness "t" of the mounting base on the tension detector side. If the length of the bolts exceeds "t", the bolts will touch the inside of the tension detector, may hinder accurate detection, and may cause a failure.

(2) Attachment using the optional plate

The pillow block and pillow block mounting bolts are not provided as standard accessories. The optional plate mounting bolts are provided as accessories with the optional plate.

● Using the automatic aligning pillow block

Make sure to use the automatic aligning pillow block as the bearing so that machining errors including imbalanced tension detection roller and non-parallel sensor mounting face and changes in the roller length caused by temperature changes are not detected as the tension. The automatic aligning pillow block can mitigate the stress caused by the inclination of the tension detection roller and the effect of deviated material path and uneven thickness.

The pillow block can mitigate the stress caused by the inclination of the tension detection roller.

The pillow block can mitigate the effect of deviated material path (when the edge position control is used) and of uneven thickness.

The pillow block can mitigate the effect of the inclination of the tension detection roller when only one tension detector is used.
5-5-2 How to attach the tension detector (Flange type)

The flange type tension detector can be attached in the following two ways.
- When attaching to the inside of the machine frame
- When attaching to the outside of the machine frame

- When attaching to the inside of the machine frame

By attaching to the inside of the machine frame, the projection on the outside of the machine frame can be eliminated (decreased). This reduces restrictions such as on the installation location of the machine. Also, the machine frame can be kept narrow.

- When attaching to the outside of the machine frame

By attaching to the outside of the machine frame, it becomes easy to install and maintain the detector.
5-5-3 Cautions on attaching the tension detector

When supporting the tension detection roller at both ends, align the height of the tension detector mounting face. Minimize the dimension marked with "*" to reduce the tension detection error. If the dimension marked with "*" is large, the material may meander, the bearing life may be shortened, and the zero-point output may change. When using the spacer for aligning the height, make sure that the shape of the spacer can cover the entire mounting face.

For the flange type tension detector, be sure to use self-aligning bearings. Using the automatic aligning bearings can mitigate the stress caused by the inclination of the tension detection roller and the effects of deviated material path and uneven thickness.

* When using in an environment with large temperature changes

When using the tension detector in an environment with large temperature changes, install a mechanism to absorb changes in the tension detection roller length caused by temperature changes so that the tension detection accuracy is not affected. For example, the effect of elongation/shrinkage of the tension detection roller caused by changes in the ambient temperature can be mitigated.

In the case of the flange type tension detector, attaching the snap ring (B) only to the tension detector on the right side enables the tension detector on the left side to slide without being fixed in the left and right directions, thus relieving the effect of expansion and contraction of the tension detection roller due to changes in the ambient temperature.

**LX-TD tension detector**

When the material is wide, use two LX-TD tension detectors in total, one at each end of the tension detection roller, so that the tension across the full width can be detected accurately even if the material is stretched on only one side. Only one LX-TD tension detector may be installed on either side when the material is not stretched on one side. Use two LX7-F tension detectors in total, one at each end.
Usage precautions

LX7-F flange-type tension detector is a precision device. Especially, the sensor part can be damaged by impact or disassembly. Please handle with care.

- Do not drop the tension detector.
- Do not touch or press the sensor part.
- Do not loosen the sensor mounting screw.
- Do not hit the tension detector when installing the tension detector to the device and when installing bearing/shaft to the tension detector.
- Do not hit the tension detector when performing centering adjustment.
- Do not pry the shaft.
- Do not apply a load which exceeds the maximum load (200% of rated load) when installing and arranging the tension detector. Do not use the tension detection roller as a foothold while working.

Usage precautions

LX7-F flange-type tension detector is a precision device. Especially, the sensor part can be damaged by impact or disassembly. Please handle with care.

- Do not drop the tension detector.
- Do not touch or press the sensor part.
- Do not loosen the sensor mounting screw.
- Do not hit the tension detector when installing the tension detector to the device and when installing bearing/shaft to the tension detector.
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- Do not pry the shaft.
- Do not apply a load which exceeds the maximum load (200% of rated load) when installing and arranging the tension detector. Do not use the tension detection roller as a foothold while working.
Chapter 6

Actuator

6-1 Types and features of actuators
6-2 Powder clutch/brake
6-3 AC servo motor and inverter/motor
6-4 Air clutches/brakes (manufactured by other companies)
6-5 Differences between control using motors and control using powder
6-6 Actuator selection flow
6-7 Selecting an actuator
Motors, clutches, brakes, etc. which move machines are called actuators.

### 6-1 Types and features of actuators

Because each actuator has advantages and disadvantages, it is necessary to select proper actuators in accordance with the purpose.

<table>
<thead>
<tr>
<th>Item</th>
<th>Type</th>
<th>Powder clutch/brake</th>
<th>Air clutch/brake</th>
<th>AC servo motor</th>
<th>Inverter (Vector control)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Torque linearity</td>
<td>3</td>
<td>3</td>
<td>4</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Torque reproducibility</td>
<td>3</td>
<td>2</td>
<td>4</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Torque control range</td>
<td>4 (1 to 100%)</td>
<td>3 (5 to 100%)</td>
<td>4 (1 to 100%)</td>
<td>3 (2 to 100%)</td>
<td></td>
</tr>
<tr>
<td>Life</td>
<td>3 (Powder)</td>
<td>2 (Pad)</td>
<td>4</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Installation cost</td>
<td>4</td>
<td>4</td>
<td>1</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Line speed</td>
<td>Low to medium</td>
<td>High</td>
<td>High</td>
<td>Medium to high</td>
<td></td>
</tr>
</tbody>
</table>

1 strongly disagree
2 disagree
3 agree
4 strongly agree
This subsection explains the types and features of actuators used in tension control.

Powder clutches/brakes are the most common actuators used for tension control. The left figure shows their principle of operation. Powder (magnetic iron powder) is filled between the drive member and the driven member. When the excitation coil applies magnetism to the powder, the torque is transmitted between the drive member and the driven member, and the equipment works as a clutch. When the driven member is fixed, the equipment works as a brake.

[Features]
1. The torque is proportional to the excitation current.
2. Continuous slip operation is available, and the torque does not change even if the slip rotation speed changes.

Applicable equipment

<table>
<thead>
<tr>
<th>Powder clutch</th>
<th>Powder brake</th>
</tr>
</thead>
<tbody>
<tr>
<td>ZKB-BN</td>
<td>ZKB-XN</td>
</tr>
</tbody>
</table>
### 6-2-2 Cautions on using powder clutches/brakes

#### [Installation]

- **Using the high-speed rotation side as the input side**
  Use the powder clutch in the regular installation status in which the high-speed rotation side is set as the input side. It is not recommended to use the powder clutch in the reverse installation status for continuous idling because the torque characteristics may deteriorate and the powder life may be shortened.

- **How to connect the input shaft and output shaft of the powder clutch/brake**
  There are mainly two methods to connect the powder clutch/brake shaft and load shaft: the method using a coupling and the method using a belt and chain. In the connection method using a coupling, use an elastic coupling, and make sure that the concentricity and squareness between the two shafts meet the values allowed for the elastic coupling that is used. In the connection method using a belt and chain, make sure that the load applied to the shaft is less than the allowable shaft load determined in accordance with the shaft strength and allowable radial load of the bearing. Refer to the corresponding catalog for the allowable shaft load.

#### [Running-in operation]

Powder inside the powder clutch/brake is distributed unevenly due to shocks applied during transportation, etc. Perform the running-in operation before starting regular operation.

To attain the original performance of the powder clutch/brake, it is important that the powder is distributed evenly inside the powder gap. If powder is distributed unevenly, the torque may become lower, fluctuate or become uneven. As a result, the powder clutch/brake cannot deliver its original performance.

The running-in operation makes unevenly distributed powder distributed evenly inside the powder gap to generate stable torque in proportion to the excitation current. Refer to the corresponding catalog or instruction manual for the running-in operation procedure.
The minimum rotation speed required for operation is determined in the powder clutch/brake. In the powder brake, the minimum rotation speed is 15 r/min. In the powder clutch, the minimum difference in the rotation speed between the input and the output is 15 r/min. (This means that both the powder clutch and the powder brake require a slip rotation speed of 15 r/min or more.)

If the slipping rotation speed is low, internal powder may be distributed unevenly and stable torque performance may not be obtained, or a considerable time may be required until the prescribed torque is achieved at startup.

The ZKB, ZKG and ZX type powder clutches/brakes can be used when the slip rotation speed becomes approximately 5 r/min.

Even if the excitation current is shut down completely, idling torque is generated in the powder clutch/brake due to the magnetism remaining in components and the friction of the powder and bearing. Torque control is available at a torque larger than the idling torque. Refer to the corresponding catalog for the idling torque shown for each model.

**Torque control**

\[ \text{Torque} (T) = W \times \frac{D}{2} \text{ [Nm]} \]

The performance of the powder clutch/brake may be unstable if the powder becomes wet. Take care to ensure that water, oil, etc. does not enter the inside. Especially when the powder clutch/brake is installed near the gear box, oil may enter the inside via the shaft. Perform complete sealing. Because the powder clutch/brake does not have a sealed structure, it cannot be used in an environment in which it is directly exposed to oil mist, oil or water.
6-3-1 What are an AC servo motor and inverter/motor?

An AC servo motor is a motor controlled so as to comply faithfully with commands.

- Commands refer to the position (motor rotation angle), rotation speed and rotation force (torque).
- The motor status in response to a command is fed back and controlled.
- A servo motor having a synchronous motor is called an AC servo motor in Mitsubishi Electric Corporation.
- An AC servo motor is a kind of inverter in a broad sense.

An inverter is a device used to convert frequency.

- An inverter for motor control refers to a device which changes the power frequency of a motor (generally an induction motor) to change the rotation speed of the motor.
- Each manufacturer generally classifies inverters into several ranks by the motor control function.

- Inverters (vector control) can control the position (motor rotation angle), rotation speed and rotation force (torque).
- Inverters (vector control) can achieve higher-quality control than general-purpose inverters for motor control though the accuracy is lower than that of AC servo motors.
- In tension control, inverters (vector control) offer higher stability of rotation speed because the inertia inside the motor is larger than that of AC servo motors.
- Inverters (vector control) offer smoother transition between the power running torque region and the regenerative torque region than AC servo motors.

The Mitsubishi Electric MELSERVO-J4 Series AC servo motors and FR-A800 Series general-purpose inverters can be operated in torque control mode to perform winding and unwinding.

In torque control mode, servo motors and inverters/motors are controlled so that a torque proportional to the command input is obtained. Accordingly, it is possible to obtain a constant tension by giving the command input in proportion to the reel diameter.
6-3-2 Cautions on using the AC servo motor and inverter (vector control)/motor

[1] The nominal motor output is determined by the rated rotation speed and output torque in continuous operation at the rated rotation speed. Large torque is required at the maximum reel diameter in winding and rewinding, and the rotation speed becomes high at the minimum reel diameter. This means that a large-capacity motor is required when the reel diameter ratio (ratio between the maximum reel diameter and the minimum reel diameter) is high. However, the motor capacity can be reduced in some cases by utilizing the constant output area. For winding and unwinding, a vector motor that can take a wide constant output area is effective.

[2] For tension control, the rated torque, not the short-time maximum torque, should be examined in the motor.

[3] Compared with the AC servo motor, the start-up delay of the motor during winding control of low tension and small reel diameter may be a problem. Care must be taken when selecting the capacity and gear ratio in winding control with large torque ratio (maximum reel diameter/minimum reel diameter × maximum tension/minimum tension).

[4] AC servo motors are generally suitable for use at high rotation speed. Their output torque is extremely small compared with powder clutches/brakes, and speed reducers are required to drive the reel shaft. If the gear ratio of the speed reducers is too high, accurate tension control cannot be achieved.

[5] When the torque command crosses the regenerative area and power running area, AC servo motors are not suitable for control requiring high accuracy because the torque linearity is not good.

[6] AC servo motors are not suitable for use at low speed because cogging torque is generated in the low-speed area.

[7] In AC servo motors, the recommended value of the load inertia moment ratio is determined for winding and unwinding against the inertia moment of motors. Refer to the corresponding catalog for details.
Air clutches/brakes (manufactured by other companies) transmit the torque by pressing the friction plate with air. Air clutches/brakes are used for winding and unwinding with relatively large torque and heat capacity compared with powder clutches/brakes. In this case, a Mitsubishi Electric tension controller can be used via an electro-pneumatic converter.

**[Features]**

- The torque is almost proportional to the air pressure.
- The torque can be changed by changing the number of calipers.
- The torque changes in accordance with the slip rotation speed.
- Friction powder is generated from the calipers and disc.
Differences between control using motors and control using powder

- **Control using motors**
  Motors are used on the side rotating the load (power running side) and the side rotated by the load (regenerative side). When motors are used for winding and unwinding:
  - Winding side: Side rotating the load (power running side)
  - Unwinding side: Side rotated by the load (regenerative side)
  On the regenerative side, the motor works as a generator, and generates electrical energy. Because the generated electrical energy returns to the AC servo amplifier or inverter, it is necessary to release it by returning it to heat or power. The regenerative unit or regenerative converter is used for this purpose.

[Rotation speed]
When driving the motor with an inverter, the torque may be insufficient if the rotation speed is low, so the tendency is to increase the gear ratio. However, if the gear ratio is too high, mechanical loss and torque fluctuation may increase. In the AC servo motor, torque ripple (torque unevenness) is generated due to the switching of the motor magnetic pole at low rotation speed. Motors are not perfect, and it is necessary to select a proper actuator in accordance with the usage conditions.

- **Control using powder**
  [Powder clutch and powder brake]
  The clutch is generally used for winding in combination with a motor. The clutch is sometimes used for unwinding in combination with a reverse rotation motor when the line speed is low. The clutch transmits the motor power to the load shaft, or shuts down the motor power. One of the features of the powder clutch is that it can transmit power while slipping. Accordingly, the powder clutch can make the rotation speed extremely low or zero on the load shaft side, which cannot be achieved by control using motors. However, slip changes into heat energy and generates heat. The brake applies braking to the power of the load shaft. Because the powder brake applies braking with slipping, slip changes into heat energy and generates heat. The generated heat reduces the powder life. In addition, it is necessary to observe the restriction on heat generation (allowable heat dissipation).
### Actuator Selection Flow

<table>
<thead>
<tr>
<th>Step</th>
<th>Description</th>
<th>Input/Output</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Confirming the machine specifications</td>
<td>Material speed, tension, reel diameter, roller diameter, etc.</td>
</tr>
<tr>
<td>2</td>
<td>Confirming the approximate actuator capacity</td>
<td>Heat generation quantity, regeneration capacity and motor capacity</td>
</tr>
<tr>
<td>3</td>
<td>Calculating the load torque and rotation speed</td>
<td>Reel shaft torque, roller torque and rotation speed</td>
</tr>
<tr>
<td>4</td>
<td>Confirming the drive shaft torque and rotation speed range</td>
<td>Checking the torque range, Confirming the rotation speed range</td>
</tr>
<tr>
<td>5</td>
<td>Temporarily selecting the model</td>
<td>Temporarily determining the actuator model</td>
</tr>
<tr>
<td>6</td>
<td>Selecting the gear ratio</td>
<td>Determining the gear ratio between the load shaft and the actuator shaft</td>
</tr>
<tr>
<td>7</td>
<td>Calculating the torque, rotation speed and regeneration capacity</td>
<td>Torque, rotation speed and heat generation quantity of the actuator shaft</td>
</tr>
<tr>
<td>8</td>
<td>Confirming the torque range and rotation speed range of the actuator shaft</td>
<td>Checking the torque range, Confirming the rotation speed range</td>
</tr>
<tr>
<td>9</td>
<td>Determining the input rotation speed for the clutch/brake</td>
<td>Input rotation speed for the clutch/brake</td>
</tr>
<tr>
<td>10</td>
<td>Confirming the allowable heat generation capacity</td>
<td>Confirming the heat generation capacity</td>
</tr>
</tbody>
</table>

The above figure shows the flow of selecting an actuator. First, confirm the machine specifications, and calculate the approximate capacity of the actuator. Next, temporarily select the model in accordance with the load shaft, torque and rotation speed. Finally, set the gear ratio, and confirm that the torque, rotation speed and capacity of the actuator shaft are acceptable.
6-7 Selecting an actuator

6-7-1 Powder brake for unwinding

This subsection shows a calculation example of a powder brake for unwinding. Calculate the torque, rotation speed and heat dissipation based on the usage conditions. The maximum value and minimum value of the braking torque required at the start and end of unwinding can be obtained as follows:

\[
T_{\text{max}} = \frac{D_{\text{max}}}{2} \times F_{\text{max}} = \frac{0.25}{2} \times 80 = 10 \text{ Nm}
\]

\[
T_{\text{min}} = \frac{D_{\text{min}}}{2} \times F_{\text{min}} = \frac{0.075}{2} \times 40 = 1.5 \text{ Nm}
\]

The maximum value and minimum value of the rotation speed can be obtained as follows:

\[
N_{\text{max}} = \frac{V_{\text{max}}}{(\pi \times D_{\text{min}})} = \frac{15}{(\pi \times 0.075)} = 63.7 \text{ r/min}
\]

\[
N_{\text{min}} = \frac{V_{\text{min}}}{(\pi \times D_{\text{max}})} = \frac{5}{(\pi \times 0.25)} = 6.4 \text{ r/min}
\]

The heat dissipation can be obtained as follows:

\[
P = 0.105 \times T \times N = 0.0167 \times F \times V = 0.0167 \times 80 \times 15 = 20 \text{ W}
\]

Select a proper powder brake model based on the above calculation results. Select a model such that the torque, rotation speed and heat dissipation do not exceed the allowable values. In these conditions, the model ZKB-1.2XN is available.
This subsection shows a calculation example of a powder clutch for winding. Calculate the torque, rotation speed and heat dissipation based on the usage conditions.

The maximum value and minimum value of the clutch torque required at the start and end of winding can be obtained as follows:

\[ T_{\text{max}} = \frac{D_{\text{max}}}{2} \times F_{\text{max}} = \frac{0.25}{2} \times 80 = 10 \text{ Nm} \]
\[ T_{\text{min}} = \frac{D_{\text{min}}}{2} \times F_{\text{min}} = \frac{0.075}{2} \times 40 = 1.5 \text{ Nm} \]

The maximum value and minimum value of the rotation speed on the output side can be obtained as follows:

\[ N_{\text{omax}} = \frac{V_{\text{max}}}{\pi \times D_{\text{min}}} = \frac{15}{\pi \times 0.075} = 63.7 \text{ r/min} \]
\[ N_{\text{omin}} = \frac{V_{\text{min}}}{\pi \times D_{\text{max}}} = \frac{5}{\pi \times 0.25} = 6.4 \text{ r/min} \]

In clutches, the rotation speed \( N_i \) on the "heat dissipation" input side should be considered also and calculated as follows:

\[ N_i = N_{\text{omax}} + 15 = 78.7 \text{ r/min} \] (Temporarily)
\[ \rightarrow 90 \text{ r/min} \] (Reduction ratio 1/20)

The heat dissipation can be obtained as follows:

\[ P = 0.105 \times T_{\text{max}} \times (N_i \times N_o) = 0.105 \times 10 \times (90 \times 6.4) = 87.8 \text{ W} \]

Because the heat dissipation varies depending on the motor rotation speed, it is necessary to select temporarily also the specifications of the winding motor to be used.

Select a powder clutch model such that the torque, rotation speed and heat dissipation do not exceed the allowable values.

In these conditions, the model ZKB-1.2BN is available.
● Selecting the winding motor

[Geared motor selection conditions]
Rotation speed: 90 r/min → Reduction ratio: 1/20
Torque: 10.0 Nm × 2 → 20 Nm or more

Safety factor

[GM-S characteristics table]

<table>
<thead>
<tr>
<th>Output (kW)</th>
<th>Rotation speed of output shaft (r/min)</th>
<th>Nominal reduction ratio</th>
<th>Actual reduction ratio</th>
<th>Allowable torque of output shaft (Nm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.2</td>
<td>60 Hz 60 Hz</td>
<td>1/3</td>
<td>1/3.07</td>
<td>3.5 2.9</td>
</tr>
<tr>
<td></td>
<td>500 180</td>
<td>1/10</td>
<td>1/9.93</td>
<td>12 9.8</td>
</tr>
<tr>
<td></td>
<td>300 120</td>
<td>1/15</td>
<td>1/14.81</td>
<td>18 15</td>
</tr>
<tr>
<td></td>
<td>75 90</td>
<td>1/20</td>
<td>1/20.08</td>
<td>24 20</td>
</tr>
<tr>
<td></td>
<td>60 72</td>
<td>1/25</td>
<td>1/23.85</td>
<td>29 25</td>
</tr>
<tr>
<td></td>
<td>50 60</td>
<td>1/30</td>
<td>1/28.88</td>
<td>33 29</td>
</tr>
<tr>
<td></td>
<td>37.5 45</td>
<td>1/40</td>
<td>1/41.07</td>
<td>47 39</td>
</tr>
<tr>
<td></td>
<td>30 36</td>
<td>1/50</td>
<td>1/48.96</td>
<td>59 49</td>
</tr>
</tbody>
</table>

[Geared motor selection result]
Output: 0.2 kW
Reduction ratio: 1/20
When the line speed is extremely low during unwinding, the input rotation speed may be lower than the minimum rotation speed in the powder brake.

In such a case, replace the powder brake with the combination of "powder clutch and reverse rotation motor". It is called reverse rotation input because the motor rotates in the reverse direction of the reel shaft rotation direction. Connect the output side (or input side) of the powder clutch to the unwinding reel shaft, connect the geared motor to the input side (or output side), and then always rotate the geared motor in the direction reverse to the rotation direction of the unwinding reel shaft. By this configuration, sufficient slip rotation speed can be secured, and stable torque control is achieved.

With regard to the powder clutch installation direction, usually connect its input side to the side of higher rotation speed. For example, when the line speed is low and the rotation speed of the unwinding reel shaft is always low, connect the input side of the powder clutch to the motor. When the reel diameter at the start of unwinding is large and sufficient slip rotation speed can be obtained during almost all operation time even though the rotation speed is temporarily low at the start of unwinding, connect the output side of the powder clutch to the motor.

### What is reverse rotation input?

- **Powder clutch**
- **Reverse rotation motor**

#### Unwinding side (Powder brake)

When the input rotation speed is lower than the minimum rotation speed in the powder brake:

<table>
<thead>
<tr>
<th>Minimum rotation speed</th>
<th>Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 r/min or less</td>
<td>ZKG, ZKB or ZX</td>
</tr>
<tr>
<td>15 r/min or less</td>
<td>ZA</td>
</tr>
</tbody>
</table>

In this case, replace the powder brake with the combination of "powder clutch + reverse rotation motor".
[Example of selecting the reverse rotation input]

This section shows an example of actually selecting the powder clutch and geared motor for reverse rotation on the unwinding side.

- When the line speed is low.

\[ V \leq 5 \text{ m/min} \]

### Selection result: Powder brake

<table>
<thead>
<tr>
<th>Conditions</th>
<th>Tension</th>
<th>Reel diameter</th>
<th>Line speed</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>F: 40 to 80 [N]</td>
<td>D: 75 to 250 [mm]</td>
<td>V: 1 to 5 [m/min]</td>
</tr>
</tbody>
</table>

Reel shaft:
- Torque: T: 1500 to 10000 [Nm]
- Rotation speed: N: 1.3 to 21.2 [r/min]
- Approximate heat dissipation: P: MAX 6.7 [W]
- Allowable heat dissipation: Pb: 95.5 [W] at 6.4 [r/min]

Calculation check:
- Tmin: 1.3 [r/min]
- Tmax: 5 [r/min]
- Nmin: 1.3 [r/min]
- Nmax: 21.2 [r/min]
- P: MAX 6.7 [W]
- Pb: 95.5 [W]

Recommended model:
- Model name: ZKB-1.2XN
- Gear ratio: R: 1
- Model data:
  - Torque: 0.12 to 12 [Nm]
  - Rotation speed: 5 to 1800 [r/min]
  - Allowable heat dissipation: 95 to 140 [W]

- Gear ratio R:
  - Calculation check:
    - Tmin: 1.3 [r/min]
    - Tmax: 5 [r/min]
    - Nmin: 1.3 [r/min]
    - Nmax: 21.2 [r/min]
    - P: MAX 6.7 [W]
    - Pb: 95.5 [W]

- Cooling method:
  - Natural cooling

Rotation speed on the output side

**Minimum value Nmin**

"1.3 r/min < 5 r/min" … NG

Reverse rotation input is effective!

- In the case of unwinding

First, select the powder brake for unwinding.

As a result of calculation with the above conditions, no powder brake is available because there is an area where the rotation speed on the output side of the brake shaft is lower than the minimum rotation speed of "5 r/min".

In such a case, reverse rotation input is effective.

Perform the calculation using the same conditions as the previous calculation.

In these conditions, the model ZKB-1.2BN is recommended.
Next, select the geared motor for reverse rotation input. Key points for selecting the motor are rotation speed and required torque.

Select a model so that the rotation speed is within the reverse rotation input range (5 to 91 r/min in this case) and the required torque is the maximum torque (10 Nm in this case) or more of the clutch. It is recommended that the motor torque is twice or more the maximum torque of the clutch to allow a margin.

When the rotation speed and torque of the motor are determined, determine the output and reduction ratio with reference to the motor characteristics table. As an example, select a geared motor from the characteristics table of the geared motor GM-S.
What is constant-slip control?

Winding side (Powder clutch)

Constant-slip control is effective when the allowable heat dissipation is smaller than the heat dissipation during operation.

Constant-slip control is effective when there is no proper powder clutch model for the winding side because the allowable heat dissipation is exceeded.

Powder clutches are often used for controlling the tension of various winding machines, but there is no proper model in some cases because the heat generation during operation exceeds the allowable heat dissipation of any powder clutch. In such a case, the heat dissipation can be reduced by decreasing the input rotation speed of the powder clutch using the inverter and tension controller.

In this method, the inverter is controlled by the speed output signal, and the input rotation speed of the powder clutch is decreased as the reel diameter becomes larger to achieve constant slip.

[Selection example for constant-slip control]

When the line speed is low

\[ V: \text{50 to 150 m/min} \]

Selection result: Powder clutch

<table>
<thead>
<tr>
<th>Conditions</th>
<th>Reel shaft</th>
<th>Powder clutch</th>
<th>Motor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tension</td>
<td>Torque</td>
<td>7.500 to 50.00 [Nm]</td>
<td></td>
</tr>
<tr>
<td>Reel diameter</td>
<td>Rotation speed</td>
<td>5.7 to 636.9 [r/min]</td>
<td></td>
</tr>
<tr>
<td>Line speed</td>
<td>Approximate heat dissipation</td>
<td>P: MAX 3084.7 [W]</td>
<td></td>
</tr>
<tr>
<td>Taper ratio</td>
<td>Gear ratio</td>
<td>R: 1</td>
<td></td>
</tr>
</tbody>
</table>

Recommended model

Model name: 2KB-40BN

Model data: Torque: 4 to 400 [Nm]
Rotation speed: 5 to 1800 [r/min]
Allowable heat dissipation: 2800 to 2800 [W]

Clutch input

<table>
<thead>
<tr>
<th>No.</th>
<th>641.9 to 642.0 [Nm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.9 to 12.5%</td>
<td></td>
</tr>
</tbody>
</table>

Rotation speed on output side

<table>
<thead>
<tr>
<th>No.</th>
<th>63.7 to 636.9 [r/min]</th>
</tr>
</thead>
<tbody>
<tr>
<td>P: 3035.8 to 3036.1 [W]</td>
<td></td>
</tr>
</tbody>
</table>

Calculation check

<table>
<thead>
<tr>
<th>Tmin</th>
<th>Tmax</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>1</td>
</tr>
</tbody>
</table>

Note: Set the clutch input freely in the above range.

Cooling method

Forced air cooling

Caution

- Closed-loop control (feedback control) is recommended because the powder clutch may be used with the torque of 5% or less.
- Minimize the mechanical loss as much as possible because the powder clutch may be used in the low torque area.
- Air piping, etc. is required separately.

This section shows an example of selecting constant-slip control.

First, select the powder clutch for winding.

As a result of calculation with these conditions, no powder clutch can be selected because the heat dissipation exceeds the allowable heat dissipation. In such a case, constant-slip control is effective.
Perform the calculation using the same conditions as the previous calculation.

In these conditions, the model ZKB-5BN is recommended.
[Selection example of motor for constant-slip control]

(1) Motor capacity
\[ P = \frac{0.0167 \times V_{\text{max}} \times F_{\text{max}} \times D_{\text{max}}}{D_{\text{min}}} = \frac{0.0167 \times 150 \times 400 \times 0.25}{0.075} = 3340 \, W \]

(2) Winding reel shaft torque
\[ T = \frac{F \times D}{2} = \frac{(200 \text{ to } 400) \times (0.075 \text{ to } 0.25)}{2} = 7.5 \text{ to } 50 \, Nm \]

(3) Winding reel shaft rotation speed
\[ N = \frac{V}{(\pi \times D)} = \frac{(3.14 \times (0.075 \text{ to } 0.25))}{(50 \text{ to } 150)} = 63.7 \text{ to } 637 \, r/min \]

(4) Motor shaft rotation speed
Suppose that the slip rotation speed of the clutch is 30 r/min
\[ N_m = N + 30 = (63.7 \text{ to } 637) + 30 = 93.7 \text{ to } 667 \, r/min \]

(5) Temporarily selecting the motor
Motor capacity: 3340 W → Rated output: 3.7 kW
Motor: SF-HRCA-3.7 K
Inverter: FR-E720-3.7 K
Rated torque: 19.6 Nm (Available torque ratio: 1:50)
Rotation speed: 3600 r/min maximum
(Rated rotation speed: 1800 r/min)
(Available rotation speed ratio: 1:100)

(6) Setting the gear ratio R
[1] From the required torque
\[ R_t = \frac{50}{19.6} = \frac{2.55}{0.25} \text{ or more should be set.} \]

[2] From the rotation speed setting
Motor rotation speed (max)
\[ R_n = \frac{3600}{667} = 5.4 \text{ or less should be set.} \]

\[ R_t < R < R_n \]
\[ 2.55 < R < 5.4 \rightarrow \text{Set } R \text{ to ”3”.} \]

(7) Motor shaft torque
\[ T' = T \times \frac{1}{R} = \frac{(7.5 \text{ to } 50)}{3} = 2.5 \text{ to } 16.7 \, Nm \]

12.8 to 85.2% of the rated torque

(8) Motor shaft rotation speed
\[ N' = N \times R = (667 \text{ to } 93.7) \times 3 = 201.1 \text{ to } 2001 \, r/min \]
7.8 to 55.6% of the maximum rotation speed
6-7-3 Motor available only in combination with an inverter (for torque control)

![Diagram of tension control system]

<table>
<thead>
<tr>
<th>Usage conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tension (F)</td>
</tr>
<tr>
<td>Reel diameter (D)</td>
</tr>
<tr>
<td>Line speed (V)</td>
</tr>
</tbody>
</table>

(1) Motor capacity

\[ P = \frac{F \times D_{\text{max}}}{D_{\text{min}}} = \frac{0.0167 \times 200 \times 100 \times 0.5}{0.09} = 1856 \text{ W} \]

(2) Winding reel shaft torque

\[ T = \frac{F \times D}{2} = \frac{(50 \text{ to } 100) \times (0.09 \text{ to } 0.5)}{2} = 2.3 \text{ to } 25 \text{ Nm} \]

(3) Winding reel shaft rotation speed

\[ N = \frac{V}{(\pi \times D)} = \frac{(100 \text{ to } 200)}{(3.14 \times (0.09 \text{ to } 0.5))} = 63.6 \text{ to } 707 \text{ r/min} \]

(4) Temporarily selecting the motor

Motor capacity: 1856 W → Rated output: 2.2 kW
Motor: SF-V5RU2K Vector control
Inverter: FR-A840-3.7K
Rated torque: 14.1 Nm (Available torque ratio: 1:50)
Rotation speed: 3000 r/min maximum
(Rated rotation speed: 1500 r/min)
(Available rotation speed ratio: 1:1500)

(5) Setting the gear ratio R

[1] From the required torque

\[ R_t = \frac{\text{Winding reel shaft torque (max)}}{\text{Motor rated torque}} = \frac{25}{14.1} = 1.77 \text{ or more should be set.} \]

[2] From the rotation speed setting

\[ R_n = \frac{3000}{707} = 4.24 \text{ or less should be set.} \]

\[ R_t < R < R_n \]

\[ 1.77 < R < 4.24 \rightarrow \text{Set } R \text{ to “2”.} \]

(6) Motor shaft torque

\[ T' = T \times \frac{1}{R} = \frac{(2.3 \text{ to } 25)}{2} = 1.15 \text{ to } 12.5 \text{ Nm} \]

8.2 to 88.7% of the rated torque

(7) Motor shaft rotation speed

\[ N' = N \times R = (63.6 \text{ to } 707) \times 2 = 127.2 \text{ to } 1414 \text{ r/min} \]

4.24 to 47.1% of the maximum rotation speed

(8) Regenerative resistor

A regenerative resistor may be required when a motor available only in combination with an inverter is used for unwinding.

Regenerative power

\[ PR = 0.0167 \times V_{\text{max}} \times F_{\text{max}} = 0.0167 \times 200 \times 100 = 334 \text{ W} \]

Resistor unit GRZG300-5Ω
(Allowable continuous power: 600 W)
6-7-4 AC servo motor (for torque control)

Usage conditions

| Tension (F) | 50 to 100 N |
| Reel diameter (D) | 90 to 500 mm |
| Line speed (V) | 100 to 200 m/min |

(1) Motor capacity
\[ P = \frac{0.0167 \times V_{\text{max}} \times F_{\text{max}} \times D_{\text{max}}}{D_{\text{min}}} = \frac{0.0167 \times 200 \times 100 \times 0.5}{0.9} = 1856 \text{ W} \]

(2) Winding reel shaft torque
\[ T = \frac{F \times D}{2} = \frac{(50 \text{ to } 100) \times (0.09 \text{ to } 0.5)}{2} = 2.3 \text{ to } 25 \text{ Nm} \]

(3) Winding reel shaft rotation speed
\[ N = \frac{V}{\pi \times D} = \frac{(100 \text{ to } 200)}{(3.14 \times (0.09 \text{ to } 0.5))} = 63.6 \text{ to } 707 \text{ r/min} \]

(4) Temporarily selecting the motor
Motor capacity: 1856 W → Rated output: 2.0 kW
Motor: HG-SR201
amplifier: MR-J4-200A
Rated torque: 19.1 Nm (Available torque ratio: 1:100)
Rotation speed: 1500 r/min maximum
(Available rotation speed ratio: 1:1500)

(5) Setting the gear ratio R
[1] From the required torque
\[ R_t = \frac{\text{Winding reel shaft torque (max)}}{\text{Motor rated torque}} = \frac{25}{19.1} = 1.3 \text{ or more should be set.} \]

[2] From the rotation speed setting
\[ R_n = \frac{1500}{707} = 2.12 \text{ or less should be set.} \]
\[ R_t < R < R_n \]
\[ 1.3 < R < 2.12 \rightarrow \text{Set } R \text{ to "2".} \]

(6) Motor shaft torque
\[ T' = T \times \frac{1}{R} = \frac{(2.3 \text{ to } 25)}{2} = 1.15 \text{ to } 12.5 \text{ Nm} \]

6.0 to 65.4% of the rated torque

(7) Motor shaft rotation speed
\[ N' = N \times R = (63.6 \text{ to } 707) \times 2 = 127 \text{ to } 1414 \text{ r/min} \]

8.4 to 94.2% of the maximum rotation speed

(8) Regenerative resistor
A regenerative resistor may be required when a motor available only in combination with an AC servo motor is used for unwinding.
Regenerative power
\[ P_R = 0.0167 \times V_{\text{max}} \times F_{\text{max}} = 0.0167 \times 200 \times 100 = 334 \text{ W} \]

Regenerative resistor built into the MR-J4-200A: 100 W
Accordingly, the external regenerative resistor MR-RB30 (Allowable regenerative power: 300 W) is required.
6-7-5 Motor available only in combination with an inverter (for speed control)

<table>
<thead>
<tr>
<th>Usage conditions</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Tension (F)</td>
<td>100 to 200 N</td>
</tr>
<tr>
<td>Reel diameter (D)</td>
<td>90 to 500 mm</td>
</tr>
<tr>
<td>Line speed (V)</td>
<td>200 to 300 m/min</td>
</tr>
<tr>
<td>Acceleration/deceleration time (t)</td>
<td>20 sec</td>
</tr>
<tr>
<td>Maximum reel shaft inertia moment (I)</td>
<td>15 kgm²</td>
</tr>
</tbody>
</table>

![Rotation speed and torque graph]

(1) Motor capacity
\[ P = \frac{0.0167 \times V_{\max} \times F_{\max} \times D_{\max}}{D_{\min}} = \frac{0.0167 \times 300 \times 200 \times 0.5}{0.09} = 5566 \text{ W} \]

(2) Required torques
[1] Shaft torque
\[ T = \frac{F \times D}{2} = \frac{(100 \text{ to } 200) \times (0.09 \text{ to } 0.5)}{2} = 4.5 \text{ to } 50 \text{ Nm} \]

\[ T_{2max} = I \times \alpha = 15 \times 1 = 15 \text{ Nm} \]

Angular acceleration: \( \alpha \) angular speed: \( \omega \)
\[ \alpha = \frac{\omega}{t} = \frac{(2\pi \times \sqrt{60})}{t} = \frac{(2\pi \times 191/60)}{20} = 1 \text{ rad}/s² \]

[3] Torque required in the reel shaft
\[ T = T_{1max} + T_{2max} = 50 \times 15 = 65 \text{ Nm} \]

(3) Winding reel shaft rotation speed
\[ N = \frac{V}{(\pi \times D)} = \frac{(200 \text{ to } 300)}{(3.14 \times (0.09 \text{ to } 0.5))} = 127 \text{ to } 1061 \text{ r/min} \]

(4) Temporarily selecting the motor
Motor capacity: 5566 W → Rated output: 7.5 kW
Motor: SF-V5RU7K
Inverter: FR-A820-11K
Rated torque: 47.7 Nm (Available torque ratio: 1:20)
Rotation speed: 3000 r/min maximum
  (Rated rotation speed: 1500 r/min)
  (Available rotation speed ratio: 1:200)

(5) Setting the gear ratio \( R \)
[1] From the required torques
\[ R_t = \frac{Winding \text{ reel shaft torque (max)}}{\text{Motor rated torque}} = \frac{65}{47.7} = 1.36 \text{ or more should be set.} \]

[2] From the rotation speed setting
\[ R_n = \frac{3000}{1061} = 2.82 \text{ or less should be set.} \]

\[ R_t < R < R_n \]
\[ 1.36 < R < 2.82 \rightarrow \text{Set } R \text{ to } "2.5". \]

(6) Motor shaft torque
\[ T' = T \times \frac{1}{R} = \frac{(4.5 \text{ to } 65)}{2.5} = 1.8 \text{ to } 26 \text{ Nm} \]
3.7 to 54.5% of the rated torque

(7) Motor shaft rotation speed
\[ N' = N \times R = (12 \text{ to } 1061) \times 2.5 = 318 \text{ to } 2653 \text{ r/min} \]
10.6 to 88.4% of the maximum rotation speed
6-7-6 AC servo motor (for speed control)

(1) Motor capacity
\[ P = \frac{0.0167 \times V_\text{max} \times F_\text{max} \times D_\text{max}}{D_{\text{min}}} = \frac{0.0167 \times 300 \times 200 \times 0.5}{0.09} = 5566 \, W \]

(2) Required torques
[1] Shaft torque
\[ T = \frac{F \times D}{2} = \frac{100 \times 200 \times 0.09 - 0.5}{2} = 4.5 \text{ to } 50 \, Nm \]

\[ T_{2\text{max}} = I \times \alpha = 1.5 \times 1 = 1.5 \, Nm \]

Angular acceleration: \( \alpha \) angular speed: \( \omega \)
\[ \alpha = \frac{\omega}{t} = \frac{(2\pi \times V/60)}{t} = \frac{(2\pi \times 91/60)}{20} = 1 \text{ rad/s}^2 \]

[3] Torque required in the reel shaft
\[ T = T_{1\text{max}} + T_{2\text{max}} = 50 \times 1.5 = 51.5 \, Nm \]

(3) Winding reel shaft rotation speed
\[ N = \frac{V}{(\pi \times D)} = \frac{200 \times 300}{3.14 \times (0.09 \times 0.5)} = 127 \text{ to } 1061 \, r/min \]

(4) Temporarily selecting the motor
Motor capacity: 5566 W → Rated output: 7 kW
Motor: HG-SR702
Servo amplifier: MR-J4-700A
Rated torque: 33.4 Nm (Available torque ratio: 1:100)
Rotation speed: 3000 r/min maximum
(Rated rotation speed: 2000 r/min)
(Available rotation speed ratio: 1:50)
Motor inertia moment: 154×10^{-4} \, kgm^2 (0.0154 \, kgm^2)
Recommended load inertia moment ratio: 15 times or less

(5) Setting the gear ratio \( R \)
[1] From the required torques
\[ R_{t} = \frac{T_{\text{winding reel shaft torque (max)}}}{T_{\text{motor rated torque}}} = \frac{51.5}{33.4} = 1.54 \text{ or more should be set.} \]

[2] From the rotation speed setting
\[ R_n = \frac{3000}{1061} = 2.82 \text{ or less should be set.} \]

\[ R_{t} < R < R_{n} \]
\[ 1.54 < R < 2.82 \rightarrow \text{Set } R \text{ to } "2.6". \]

(6) Motor shaft torque
\[ T' = T \times \frac{1}{R} = \frac{(4.5 \text{ to } 51.5)}{2.6} = 1.7 \text{ to } 19.8 \, Nm \]

5.4 to 66.5% of the rated torque

(7) Motor shaft rotation speed
\[ N' = N \times R = (127 \text{ to } 1061) \times 2.6 = 330 \text{ to } 2759 \, r/min \]

11 to 92% of the maximum rotation speed

(8) Load inertia moment ratio
\[ \frac{N}{R^2} = \frac{\text{(Motor inertia moment) x (Load inertia moment ratio)}}{R} \]
\[ \frac{1.5}{2.6} < \frac{0.0154 \times 15}{R} \]
\[ 0.221 < 0.231 \rightarrow \text{OK} \]
When selecting an actuator

First, learn the features of various actuators, identify the machine specifications, and then select a proper actuator. Next, perform detailed calculations for selection, and check whether the temporarily selected actuator meets the intended specifications. It is necessary to examine actuators carefully because selecting a proper actuator has the largest impact on machine performance and economic efficiency.
Chapter 7

Basis of Tension Control System Construction

7-1 Basic tension control system
7-2 Configuration of the tension control system
7-3 Taper tension control
When constructing an actual tension control system, it is necessary to set the machine specifications suitable for each material and to construct a system that meets the machine specifications. The machine specifications differ with different materials, and the system configuration differs considerably when the machine specifications are different.

### 7-1 Basic tension control system

#### 7-1-1 System having only the unwinding section and winding section

The simplest tension control system is a machine which unwinds and winds a material. In such a system, the speed should be controlled in either the unwinding section or winding section regarded as the pulling side, and the other section should be controlled as the pulled side. The pulling side works as the main shaft in the system.

In the system shown in the left figure, the unwinding section is controlled by the powder brake. The powder brake is an actuator designed for torque control, and can work only as the pulled side. Accordingly, the tension should be controlled on the unwinding section. On the other hand, the winding motor should control the speed so that the peripheral speed of the wound material is kept constant even if the reel diameter changes.

The winding section working as the pulling side can be controlled by the torque or speed. Even if several free rollers are installed in the intermediate section, the tension from the unwinding section to the winding section is determined by the result of unwinding control in this system.
**Configuration example**

In the configuration without intermediate shafts, either the winding reel shaft or the unwinding reel shaft is controlled by the torque, and the other shaft is controlled by the speed.

In example (1), the unwinding reel shaft is controlled by the torque, and the winding reel shaft is controlled by the speed. In example (2), the unwinding reel shaft is controlled by the speed, and the winding reel shaft is controlled by the torque.

Actuators for torque control include powder clutches/brakes, servo motors (in torque control mode), inverters/motors (equipped with encoder), etc. Actuators for speed control include servo motors (in speed control mode), inverters/motors (not equipped with encoder), etc. The regenerative unit is required separately when the motor is used on the regenerative side (for braking).

(1) Unwinding side: Torque control, winding side: Speed control

(2) Unwinding side: Speed control, winding side: Torque control

**7-1-2 System having an intermediate main shaft**

The left figure shows the basic tension control system in which the main shaft is added in the intermediate section of the machine shown in Subsection 7-1-1. The intermediate nip roll keeps the material speed constant. The material speed can become uneven due to the eccentricity of the wound material in the machine shown in Subsection 7-1-1. On the other hand, the material speed is stable in this system because the external shape of the nip roll installed in the intermediate section does not change.

In this system, the control should be such that the main shaft works as the pulling side in the relationship between the unwinding reel shaft and the main shaft and between the winding shaft and the main shaft. The control method can be determined freely for the winding reel shaft which winds the material fed from the unwinding reel shaft (pulled side) or main shaft.

In the left figure, the unwinding reel shaft is controlled by the speed using the dancer roll and inverter, and the winding reel shaft is controlled by the torque using the powder clutch. The tension is constant from unwinding to winding in the machine shown in Subsection 7-1-1, but the tension for unwinding (from the main shaft to the unwinding reel shaft) and the tension for winding (from the main shaft to the winding reel shaft) can be controlled separately in this system.
The main shaft is controlled by the speed. If the driving force of the main shaft is insufficient, the material speed may be unstable due to changes in the tension for unwinding or winding. In addition, the force caused by the inertia of the entire machine is applied to the main shaft during acceleration or deceleration.

Accordingly, the main shaft should have a driving force that can control the material stably at a constant speed even if the tension for unwinding or winding changes or if the acceleration or deceleration of the machine causes an effect.
Configuration example

In a system having an intermediate main shaft, control the unwinding reel shaft and winding reel shaft by the torque or speed, and control the intermediate shaft by the speed. Four types of combination are available as shown below.

Actuators for torque control include powder clutches/brakes, servo motors (in torque control mode), inverters/motors (equipped with encoder), etc.

Actuators for speed control include servo motors (in speed control mode), inverters/motors (not equipped with encoder), etc.

The regenerative unit is required separately when the motor is used on the regenerative side (for braking).

(1) Unwinding side: Torque control, winding side: Torque control

(2) Unwinding side: Torque control, winding side: Speed control

(3) Unwinding side: Speed control, winding side: Torque control

(4) Unwinding side: Speed control, winding side: Speed control
### 7-1-3 Advantages and disadvantages of the intermediate shaft

<table>
<thead>
<tr>
<th>Intermediate shaft</th>
<th>Unwinding</th>
<th>Winding</th>
<th>Advantage</th>
<th>Disadvantage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Not installed</td>
<td>Torque control</td>
<td>Speed control</td>
<td>- The configuration is simple because the main shaft works also as the winding reel shaft. (A separate main shaft does not exist.)</td>
<td>- The tension for winding and tension for unwinding cannot be set separately.</td>
</tr>
<tr>
<td></td>
<td>Speed control</td>
<td>Torque control</td>
<td>- The material surface is not damaged because the material is not nipped.</td>
<td>- The speed fluctuates considerably compared with the system in which the main shaft is set separately.</td>
</tr>
<tr>
<td>Installed</td>
<td>Torque control</td>
<td>Torque control</td>
<td>- The line speed is stable. - Because the material is nipped by the intermediate shaft, the tension for winding and tension for unwinding can be set separately. - The system can cope with low tension because the motor can positively feed out the material when the dancer roll is used.</td>
<td>- An actuator is required for each of the winding reel shaft, unwinding reel shaft and main shaft.</td>
</tr>
<tr>
<td></td>
<td>Speed control</td>
<td>Torque control</td>
<td>- The dancer roll mitigates fluctuations of the tension even if the machine accelerates or decelerates.</td>
<td>- The material surface may be damaged because the material is nipped.</td>
</tr>
</tbody>
</table>

Powder clutches/brakes are suitable for torque control at low line speed, and motors are suitable for torque control at high line speed.

Actuators for torque control: Powder clutches/brakes, servo motors (in torque control mode), inverters/motors (equipped with encoder), etc.

Actuators for speed control: Servo motors (in speed control mode), inverters/motors (not equipped with encoder), etc.
The tension of the material fed in the machine is changed in each process. In addition, the role of tension control is different in each section of the machine. Accordingly, it is necessary to change over the control in each section of the machine even for a material that is fed continuously. To achieve the changeover of control, driving rolls are installed in the middle of the machine for dividing each control section.

Nip rolls which nip the material from above and from below are generally used as the mechanism for driving the material in the middle. Nip rolls usually nip the material with a constant pressure given by the air cylinder.

If the material cannot be nipped due to the nature of the processes, the material may be wound around rubber rolls so that the surface friction of the driving rolls becomes as large as possible.
It is essential that the machine has only one main shaft and that its speed is controlled. The main shaft determines the processing speed of the entire machine, and other driving shafts should follow the main shaft to feed the web stably. The main shaft works as the leader of the entire machine. In the same way that a human leader should exert leadership to control, conduct and lead a group, the main shaft should have sufficient force to lead the entire machine properly. The term "force" here refers to sufficiently stable speed control and torque. The material is affected by three types of forces (torques): "force of the tension", "force caused by the inertia" and "force caused by mechanical friction". The main shaft should rotate stably even if these forces change successively. Especially when the machine accelerates or decelerates, the torque caused by the inertia of all rotating parts of the machine is applied to the main shaft. This fact should be considered when selecting the actuator for the main shaft.

Unwinding control
Unwinding control is performed in the area from the reel from which the material is unwound to the first driving roll. Unwinding control is required to unwind the material whose diameter changes at a constant tension. In unwinding control, the driving roll should work as the pulling side and the unwinding reel shaft should work as the pulled side. In some machines including resin film forming machines, the unwinding section does not exist because resin is fed out continuously in a film shape.

1-shaft unwinding mechanism
The brake is installed in the reel shaft. Because of the relationship "Unwinding tension = Braking torque/Unwinding radius", a constant tension can be achieved when the braking torque is decreased in accordance with the decrease of the reel diameter. A speed increaser and speed reducer such as gear and pulley are installed as necessary between the reel shaft and the brake.
Simultaneous multi-shaft unwinding mechanism

In the single cutter (overlapped paper cutting machine), yarn sizing machine and film laminator, long materials wound around multiple reels are unwound at the same time. When overall tension control is performed, the torque of each brake should be even. The intended tension (tension set value) is changed in accordance with the thickness, width, strength, etc. of the material. In addition, because the reel diameter is always changing, each brake should have sufficient performance to adjust the torque in a wide range.

Unwinding mechanism with motor

- Positive unwinding mechanism
  In the following cases, the reel shaft may be driven by the motor to achieve positive unwinding:
  - When the reel is heavy, and manual operations such as initial paper passing should be made easy
  - When the peripheral speed of the preparatory reel should be controlled so that it becomes equivalent to the unwinding speed of the currently used reel in the automatic paper splicing device (auto paster)
  - When the tension caused by mechanical loss of the unwinding shaft is high compared with the intended unwinding tension
  - When the acceleration tension caused by the reel inertia is high at startup (Positive unwinding and compensation of the mechanical loss or inertia are required.)

In the above cases, tension control by the speed using the dancer roll mechanism is generally required.

Unwinding mechanism driven by reverse rotation

In the following cases, the motor and clutch are used instead of the brake to drive the reel by reverse rotation:

- When the material is wound and unwound between a pair of reels in the rewinding machine
- When the rotation speed of the brake is 5 r/min (15 r/min in the ZA type) or less on the unwinding side
Winding control is performed in the reel which winds the material from the final driving roll.

In the machine adopting winding control, the material should be wound into a neat shape because the material will be used in the next machine. To achieve a neat shape, the tension is not kept constant, but is decreased gradually as the reel diameter increases (taper tension) in some cases. Alternatively, a mechanism to prevent the involvement of air during winding may be installed.

In winding control also, the driving roll should work as the pulling side and the winding shaft should work as the pulled side. In some machines in which the cut status is the final product such as newspaper printing machines and cutters, winding control is not performed.
The material winding speed is kept constant by the rotation speed of the feed roll. The torque of the clutch is increased as the winding reel diameter increases to keep the tension constant.

Though the input rotation speed of the clutch is constant, the rotation speed on the output side decreases and the slip rotation speed (difference between the input rotation speed and the output rotation speed) increases as the reel diameter increases.

The speed reduction mechanism such as gear and pulley is installed as necessary in the input shaft and output shaft of the clutch.

Heat generation in the clutch and brake is proportional to the product of the slip rotation speed and transmission torque. In the unwinding brake, the heat generation amount is always constant because the slip rotation speed is low when the torque is high (that is, the reel diameter is large) and the torque is small when the slip rotation speed is high (that is, the reel diameter is small).

In the case of a clutch, the slip rotation speed is high when the torque is high, and thermally unfavorable phenomena may occur. A large-sized motor is required for winding in the same way. The unwinding power (W) can be calculated approximately by the expression \(0.0167 \times \text{Line speed (m/min)} \times \text{Tension (N)}\).

By using the tension controller having the slip rotation speed control function, it is possible to control the rotation speed of the winding motor so that the slip rotation speed of the winding clutch becomes constant without regard to the reel diameter. This can decrease the heat dissipation of the clutch.
[Multi-shaft winding mechanism]

In the slitter (which cuts a wide sheet into tape) and separator (which separates a laminated sheet and winds it), the clutches may be installed in multiple reel shafts and controlled by one winding motor as shown in the left figure.

[Continuous winding mechanism]

When both automatic paper splicing & unwinding and automatic paper splicing & winding are performed at the same time, an accumulator is installed (for paper splicing while winding is stopped) in some cases and is not installed (for paper splicing while winding is performed) in other cases.

When an accumulator is not installed, predrive control is required to match the peripheral speed. The left figure shows the 2-shaft winding mechanism in which out-feed control is adopted in the continuous winding method (without the accumulator).

In the winding mechanism, the clutch and motor are installed in the turret arm in some cases, and installed on the stationary side in other cases.

[Surface winding]

The area around the reel shaft is in contact with the under-roll by the pressure from the press roll. The clutch controls the under-roll driving torque to achieve a constant tension.
Intermediate shaft control is performed in the area from the first driving roll to the last driving roll in the machine. The unwinding side from the main shaft (area between the unwinding reel and the feed roll) is called in-feed, and the winding side from the main shaft (area between the winding reel and the feed roll) is called out-feed.

The in-feed area is designed to assure stable tension of the material unwound by unwinding control before processing and to prevent shocks generated by changeover of the unwound material from being transmitted to the processing section. The out-feed area is designed to prevent fluctuations in the winding tension from being transmitted to the processing section. Because the tension changes by taper tension control in winding control, the out-feed area cuts the tension so that changes in tension do not affect the processing section. The out-feed area also prevents shocks generated by changeover of the wound material from being transmitted to the processing section.

In-feed mechanism

The clutch and brake are installed in the in-feed roll shaft to enable reversible torque control. By this mechanism, the tension in the unwinding section and the tension in the paper feed section can be set independently. For example, the unwinding tension becomes smaller than the paper feed tension when the brake is applied, and the unwinding tension becomes higher than the paper feed tension when the clutch is driven. In addition, the in-feed mechanism can correct tension fluctuations of long cycle in the unwinding section. When the in-feed roll and feed roll are driven by separate motors, servo motors may be used instead of the clutch-brake mechanism.
7-3 Taper tension control

Taper tension control

Taper tension control (taper control) refers to the control which changes the tension in accordance with changes in the reel diameter.

Taper control is mainly used for winding control. The tension is decreased as the reel diameter increases so that the material is not wound too tightly or not displaced during winding.

The taper ratio refers to the inclination of tension decrease against constant tension control as shown in the left figure.

Broken line taper tension control

Broken line taper tension control refers to taper tension control which changes the taper ratio in the intermediate reel diameter without using the same taper ratio from the initial diameter to the final diameter.

Point!

Construction of the tension control system

- Determining the main shaft in the machine used as the reference of the speed
- Dividing control sections, and installing nip rolls
- Determining the control type (speed control or torque control) to be adopted in each control section
- Determining the control method (dancer roll or tension detector)
Chapter 8

Application Examples

8-1 Business form printing machine
8-2 Offset printing machine
8-3 Gravure printing machine
8-4 Screen printing machine
8-5 Unwinder
8-6 Punching machine
8-7 Inflatable extruder + 2-shaft film winder
8-8 Multiple cutter
8-9 Slitter (1)
8-10 Laminator
8-11 Rolling machine
8-12 Film cleaning machine
8-13 Plating machine
8-14 Winder
8-15 Thickness measuring instrument
8-16 Steel plate plating line
8-17 Static electricity eliminating device
8-18 Slitter (2)
8-19 Laminator
8-20 Film processing machine
8-1 Business form printing machine

Features

- The feedback type tension controller is used to prevent color shift in printing and improve the pitch accuracy of punched holes used for feed to the printer.
- The stall memory function is effective in the inching operation for color matching during printing to reduce color shift and pitch deviation at restart.
- When the machine decelerates immediately before the base paper runs short, the deceleration gain is utilized to reduce color shift and pitch deviation caused by slackness.
- The powder brake is the thermo block cooling type which does not require water piping.

Usage conditions

<table>
<thead>
<tr>
<th>Workpiece material</th>
<th>Unwinding</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tension N</td>
<td>100 to 200</td>
</tr>
<tr>
<td>Line speed m/min</td>
<td>250 or less</td>
</tr>
<tr>
<td>Reel diameter φ</td>
<td>95 to 800</td>
</tr>
</tbody>
</table>

Applicable models

- Powder brake: ZKB-5HBN
- Tension controller: LE7-40GU-L
- Tension detector: LX-050TD

• The feedback type tension controller is used to prevent color shift in printing and improve the pitch accuracy of punched holes used for feed to the printer.
• The stall memory function is effective in the inching operation for color matching during printing to reduce color shift and pitch deviation at restart.
• When the machine decelerates immediately before the base paper runs short, the deceleration gain is utilized to reduce color shift and pitch deviation caused by slackness.
• The powder brake is the thermo block cooling type which does not require water piping.
8-2 Offset printing machine

**Features**

- Fully-automatic paper splicing (auto pasted) may be performed in the paper feed section to save labor.
- In tension control, the reel diameter is detected and fed back for automatic paper splicing.
- The stall memory function is effective in the inching operation for color matching during printing to reduce color shift and pitch deviation at restart.
- When the machine decelerates immediately before the base paper runs short, the deceleration gain is utilized to reduce color shift and pitch deviation caused by slackness.

**Usage conditions**

<table>
<thead>
<tr>
<th></th>
<th>Unwinding</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tension</td>
<td>N 200 to 300</td>
</tr>
<tr>
<td>Line speed</td>
<td>m/min 500 or less</td>
</tr>
<tr>
<td>Reel diameter</td>
<td>φ 100 to 1000</td>
</tr>
</tbody>
</table>

**Applicable models**

- **Vector inverter**: FR-A820-55K + FR-A8AP (option)
- **Motor**: SF-V5RU37K
- **Tension controller**: LD-10WTB-CCL + LD-10WTB-DCA + LM-10WA-TAD or LE-10WTA-CCL + LD-10WTB-DCA x 2 units
- **Tension detector**: LX-050TD

---

To processing section

Tension detector LX-050TD

Proximity switch

Motor SF-V5RU37K

Inverter FR-A820-55K + FR-A8AP

Regenerative unit

Tension controller

LD-10WTB-CCL
LD-10WTB-DCA
LM-10WA-TAD

Rotary encoder
8-3 Gravure printing machine

**Features**
- Two shafts in the unwinding section and two shafts in the winding section are driven by the vector inverters in torque control mode.
- The system is connected to the CC-Link, and operated through the network.

**Usage conditions**

<table>
<thead>
<tr>
<th></th>
<th>Unwinding</th>
<th>Winding</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tension (N)</td>
<td>30 to 150</td>
<td>30 to 150</td>
</tr>
<tr>
<td>Line speed (m/min)</td>
<td>200 or less</td>
<td>200 or less</td>
</tr>
<tr>
<td>Reel diameter (φ)</td>
<td>100 to 700</td>
<td>100 to 700</td>
</tr>
</tbody>
</table>

**Applicable models**

<table>
<thead>
<tr>
<th></th>
<th>Fr-A820-7.5K + Fr-A8AP (option)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vector inverter</td>
<td>Fr-A820-7.5K</td>
</tr>
<tr>
<td>Motor</td>
<td>SF-V5RI5K</td>
</tr>
<tr>
<td>Tension controller</td>
<td>LD-10WTB-CCL + LD-10WTB-DCA + LM-10WA-TAD or LE-10WTA-CCL + LD-10WTB-DCA x 2 units</td>
</tr>
<tr>
<td>Tension detector</td>
<td>LX-030TD</td>
</tr>
</tbody>
</table>
8-4 Screen printing machine

Features

- This system is applicable to machines which require intermittent feed in the processing section.
- The processing section performs intermittent operation. The material is made slack at the exit of the processing section to absorb the intermittent operation in the processing section, and the winding section performs continuous operation.
- The amount of slack at the exit of the processing section is detected by the sensor, and the intermittent roll speed is changed over so that the amount of slack is controlled to be within the prescribed range.

Usage conditions

<table>
<thead>
<tr>
<th></th>
<th>In-feed area</th>
<th>Winding</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tension</td>
<td>N</td>
<td>1 to 1.5</td>
</tr>
<tr>
<td>Line speed</td>
<td>m/min</td>
<td>1</td>
</tr>
<tr>
<td>Reel diameter</td>
<td>φ</td>
<td>100</td>
</tr>
</tbody>
</table>

Applicable models

<table>
<thead>
<tr>
<th>In-feed</th>
<th>Winding</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power amplifier</td>
<td>LD-10PAU-A</td>
</tr>
<tr>
<td>Powder brake</td>
<td>ZKG-SYN</td>
</tr>
<tr>
<td>Tension controller</td>
<td>LE7-40GU-L</td>
</tr>
<tr>
<td>Geared motor</td>
<td>0.1 kW 1/50</td>
</tr>
<tr>
<td>Powder clutch</td>
<td>ZKB-0.3AN</td>
</tr>
<tr>
<td>Tension detector</td>
<td>LX7-50FN17</td>
</tr>
</tbody>
</table>
- Because the torque control range is wide, two powder brakes are used together or only one powder brake is used at a time in accordance with the tension value.
- When the tension F is 200 to 500 N, two powder brakes (ZKB-40HBN) are used. When the tension F is 50 to 270 N, only one powder brake (ZKB-40HBN) is used. (It is necessary to separate the unused powder brake (ZKB-40HBN) using another clutch mechanism so that the idling torque does not cause an effect while the tension is low.)
- This system is applicable to unwinding control of large capacity. Because the available range of the braking torque control ratio is increased by changing over the number of used brakes in accordance with the tension value, this system is suitable for applications in which the difference in the used tension is large and applications in which the reel diameter ratio is high.

**Usage conditions**

<table>
<thead>
<tr>
<th></th>
<th>Unwinding</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tension</td>
<td>50 to 500</td>
</tr>
<tr>
<td>Line speed</td>
<td>50 to 700</td>
</tr>
<tr>
<td>Reel diameter</td>
<td>96 to 1100</td>
</tr>
</tbody>
</table>

**Applicable models**

<table>
<thead>
<tr>
<th></th>
<th>Unwinding</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tension controller</td>
<td>LE7-40GU-L</td>
</tr>
<tr>
<td>Power amplifier</td>
<td>LE-50PAU</td>
</tr>
<tr>
<td>Powder brake</td>
<td>ZKB-40HBN</td>
</tr>
<tr>
<td>Tension detector</td>
<td>LX-100TD</td>
</tr>
</tbody>
</table>
8-6 Punching machine

- The material does not travel but is fed intermittently during punching. This system controls the tension in the winding section.

- Though the material is fed intermittently, the geared motor for winding is always rotating so that the material is stretched properly even in the stop status.

- Because intermittent operation is required, the reel diameter detection type tension controller, which offers stable control, is adopted.

- Because the material thickness is 200 μm, the reel shaft pulse number is set to "10 pulses/rotation" and the material thickness is set to "20 μm (= 200 × 1/10)".

- This system is applicable to machines requiring intermittent feed such as hot stamping machines and screen printing machines.

**Features**

<table>
<thead>
<tr>
<th>Usage conditions</th>
<th>Winding</th>
<th>Material</th>
<th>Applicable models</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tension</td>
<td>50 to 100</td>
<td>Paper (Thickness: 200 μm)</td>
<td>Tension controller</td>
</tr>
<tr>
<td>Line speed</td>
<td>6 or less</td>
<td></td>
<td>Powder clutch</td>
</tr>
<tr>
<td>Reel diameter</td>
<td>92 to 500</td>
<td></td>
<td>Geared motor</td>
</tr>
</tbody>
</table>

**Applicable models**

<table>
<thead>
<tr>
<th>Winding</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tension controller</td>
</tr>
<tr>
<td>Powder clutch</td>
</tr>
<tr>
<td>Geared motor</td>
</tr>
<tr>
<td>LD-30FTA</td>
</tr>
<tr>
<td>ZKB-2.5BN</td>
</tr>
<tr>
<td>0.2 kW 1/60</td>
</tr>
</tbody>
</table>
### Features

- The inflatable extruder extrudes polyethylene film into a cylindrical shape. The cylindrical film is folded in half, cut at both edges, and shaped into two sheets.

- The material film is cooled in this period, and each of the two sheets is wound by the 2-shaft turret type automatic winder respectively. Tension control equipment is used also in this type of application.

- Because the LE7-40GU-L incorporates the new shaft preset (new shaft predrive output) function, a simple parameter setting procedure enables automatic paper splicing using the 2-shaft turret machine.

- Because the LE7-40GU-L incorporates the cut gain (cut torque) function, film can be cut easily.

- This system is applicable to shaft changeover machines using the powder clutch.

### Usage conditions

<table>
<thead>
<tr>
<th></th>
<th>Winding</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tension N</td>
<td>15 to 25</td>
</tr>
<tr>
<td>Line speed m/min</td>
<td>50 to 150</td>
</tr>
<tr>
<td>Reel diameter φ</td>
<td>100 to 900</td>
</tr>
</tbody>
</table>

### Applicable models

<table>
<thead>
<tr>
<th></th>
<th>Winding</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tension controller</td>
<td>LE7-40GU-L × 2 units</td>
</tr>
<tr>
<td>Tension detector</td>
<td>LX7-150FN17</td>
</tr>
<tr>
<td>Powder clutch</td>
<td>ZKB-5BN (Forced air cooling)</td>
</tr>
<tr>
<td>Geared motor</td>
<td>1.5 kW 1/10</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Protective element</th>
</tr>
</thead>
<tbody>
<tr>
<td>Commutation diode</td>
<td>200 VA 5 A</td>
</tr>
<tr>
<td>Protective resistor</td>
<td>10 W 47 Ω</td>
</tr>
</tbody>
</table>

When the reel is changed over between two shafts, the powder clutch is changed over by the external contact. Make sure to install the protective diode and resistor in parallel with two powder clutches.
8-8 Multiple cutter

- Because several sheets of paper are cut all at once, the tension of every sheet is kept constant to reduce the dimensional misalignment.
- The reel diameter is detected in the representative reel, and four powder brakes are controlled.
- The diameter of the four reels in the unwinding section must be the same.
- Adjustment variable resistors are used to fine-adjust the tension of each shaft.
- This system is applicable to multi-shaft unwinding in the sizing machine, etc.

**Features**

**Usage conditions**

<table>
<thead>
<tr>
<th>Material</th>
<th>Paper</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tension   N</td>
<td>300 to 500</td>
</tr>
<tr>
<td>Line speed  m/min</td>
<td>60 to 100</td>
</tr>
<tr>
<td>Reel diameter  μ</td>
<td>100 to 1200</td>
</tr>
</tbody>
</table>

**Applicable models**

<table>
<thead>
<tr>
<th>Material</th>
<th>Paper</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tension controller</td>
<td>LD-10WTB-CCL</td>
</tr>
<tr>
<td>Power amplifier</td>
<td>LE-50PAU x 4 units</td>
</tr>
<tr>
<td>Powder brake</td>
<td>ZA-40Y x 4 units</td>
</tr>
</tbody>
</table>
This system is used when the material is slit by the knife and wound by multiple shafts, and the tension of each shaft is controlled at the same time.

- The proximity switch and pulse generator are connected directly to the representative reel shaft and roll shaft, the pulses from these shafts are input to the tension controller, and then the reel diameter is calculated in the calculation circuit built into the tension controller. This system adopts open-loop control, and hunting does not occur.

- Adjustment variable resistor are used together to eliminate the difference in tension caused by dispersion in the material width among the shafts and by dispersion in the clutch torque.

- This system is applicable to any type of simultaneous multi-shaft winding.

**Usage conditions**

<table>
<thead>
<tr>
<th>Winding</th>
<th>Material</th>
<th>Film</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tension N</td>
<td>100 or less</td>
<td></td>
</tr>
<tr>
<td>Line speed m/min</td>
<td>100 or less</td>
<td></td>
</tr>
<tr>
<td>Reel diameter φ</td>
<td>110 to 400</td>
<td></td>
</tr>
</tbody>
</table>

**Applicable models**

<table>
<thead>
<tr>
<th>Winding</th>
<th>Material</th>
<th>Film</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tension controller</td>
<td>LD-10WTB-CCL</td>
<td></td>
</tr>
<tr>
<td>Powder clutch ZKB-5BN (Forced air cooling)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Geared motor</td>
<td>3.7 kW 1/3</td>
<td></td>
</tr>
<tr>
<td>Power amplifier LE-50PAU</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Features**

- This system is used when the material is slit by the knife and wound by multiple shafts, and the tension of each shaft is controlled at the same time.

- The proximity switch and pulse generator are connected directly to the representative reel shaft and roll shaft, the pulses from these shafts are input to the tension controller, and then the reel diameter is calculated in the calculation circuit built into the tension controller. This system adopts open-loop control, and hunting does not occur.

- Adjustment variable resistor are used together to eliminate the difference in tension caused by dispersion in the material width among the shafts and by dispersion in the clutch torque.

- This system is applicable to any type of simultaneous multi-shaft winding.
8-10 Laminator

- The reel diameter is detected in one representative shaft, and unwinding is controlled simultaneously in multiple shafts.
- This system is designed for general 2-shaft unwinding control in such a configuration that the reel diameter calculation adapter LD-10WTB-DCA is connected to the tension controller LD-10WTB-CCL.
- This system is applicable to any type of simultaneous multi-shaft unwinding.

### Usage conditions

<table>
<thead>
<tr>
<th></th>
<th>Unwinding</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tension (N)</td>
<td>20 to 200</td>
</tr>
<tr>
<td>Line speed (m/min)</td>
<td>2 to 20</td>
</tr>
<tr>
<td>Reel diameter (φ)</td>
<td>110 to 400</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Material</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Film</td>
</tr>
</tbody>
</table>

### Applicable models

<table>
<thead>
<tr>
<th></th>
<th>Unwinding</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tension controller</td>
<td>LD-10WTB-CCL + LD-10WTB-DCA</td>
</tr>
<tr>
<td>Power amplifier</td>
<td>LD-10PAU-A × 2 units</td>
</tr>
<tr>
<td>Powder brake</td>
<td>ZKB-0.6YN</td>
</tr>
</tbody>
</table>
The air brake and load cell control the tension for unwinding at high tension of metallic materials such as thin steel plate and aluminum plate.

Because the tension is high, a commercial load cell is used as the detector, and the detected load is input to the tension controller.

This system is applicable also to winders requiring high tension.

<table>
<thead>
<tr>
<th>Usage conditions</th>
<th>Unwinding</th>
<th>Material</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tension N</td>
<td>10000 or less</td>
<td>Thin steel plate</td>
</tr>
<tr>
<td>Line speed m/min</td>
<td>70 or less</td>
<td></td>
</tr>
<tr>
<td>Reel diameter φ</td>
<td>250 to 1200</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Applicable models</th>
<th>Unwinding</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tension controller</td>
<td>LE-10WTA-CCL</td>
</tr>
<tr>
<td>Air brake</td>
<td>Product manufactured by another company</td>
</tr>
<tr>
<td>Electro-pneumatic converter</td>
<td>Product manufactured by another company</td>
</tr>
</tbody>
</table>
8-12 **Film cleaning machine**

- Because the speed is low, reverse rotation input of the powder clutch is used for unwinding to stabilize the tension.
- The tension is monitored before and after the cleaning section to check for mechanical loss. (When there is considerable mechanical loss, a drive motor for mechanical loss correction is installed.)
- Because the tension is low, the dancer roll is used to apply the tension.

### Usage conditions

<table>
<thead>
<tr>
<th>Unwinding</th>
<th>Winding</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tension N</td>
<td>20 to 200</td>
</tr>
<tr>
<td>Line speed m/min</td>
<td>0.1 to 6</td>
</tr>
<tr>
<td>Reel diameter μ</td>
<td>Max. 400</td>
</tr>
<tr>
<td>Thickness</td>
<td>100 to 200 μm</td>
</tr>
<tr>
<td>Width</td>
<td>Max. 700 mm</td>
</tr>
<tr>
<td>Mass</td>
<td>250 kg</td>
</tr>
</tbody>
</table>

### Applicable models

<table>
<thead>
<tr>
<th>Unwinding</th>
<th>Winding</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tension controller LE7-40GU-L</td>
<td>Tension controller LE7-40GU-L</td>
</tr>
<tr>
<td>Tension detector LX7-300FN17</td>
<td>Tension detector LX7-300FN17</td>
</tr>
<tr>
<td>Powder clutch ZKB-5BN</td>
<td>Powder clutch ZKB-5BN</td>
</tr>
<tr>
<td>Geared motor 0.4 kW 1/50</td>
<td>Geared motor 0.4 kW 1/50</td>
</tr>
<tr>
<td>In-feed area</td>
<td>In-feed area</td>
</tr>
<tr>
<td>Tension meter LM-10WA-CCL</td>
<td>Tension meter LM-10WA-CCL</td>
</tr>
<tr>
<td>Tension detector LX-030TD</td>
<td>Tension detector LX-030TD</td>
</tr>
</tbody>
</table>
8-13 Plating machine

Features

- The powder clutch is used for the accumulator and dancer roll. The tension can be changed by setting the power amplifier.
- Two shafts are switched over using the stop roll in winding, and plating can be continued even when the shaft is switched over.

Usage conditions

<table>
<thead>
<tr>
<th>Usage conditions</th>
<th>Dancer roll area</th>
<th>Out-feed area</th>
<th>Accumulator area</th>
<th>Winding section</th>
<th>Workpiece material</th>
<th>Metallic foil</th>
<th>Thickness</th>
<th>Width</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tension N</td>
<td>200 to 500</td>
<td>400 to 1000</td>
<td>500</td>
<td>1200 or less</td>
<td>Metallic foil</td>
<td>10 μm (Initial value)</td>
<td>410 μm after treatment</td>
<td></td>
</tr>
<tr>
<td>Line speed m/min</td>
<td>5 to 20</td>
<td>5 to 20</td>
<td>5 to 20</td>
<td>5 to 20</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reel diameter φ</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>75 to 300</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Applicable models

<table>
<thead>
<tr>
<th>Dancer roll area</th>
<th>Accumulator area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power amplifier LE-50PAU</td>
<td>Power amplifier LE-50PAU</td>
</tr>
<tr>
<td>Powder clutch ZA-20A1</td>
<td>Powder clutch ZA-20A1</td>
</tr>
<tr>
<td>Geared motor 1.5 kW 1/50</td>
<td>Geared motor 1.5 kW 1/50</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Out-feed area</th>
<th>Winding</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tension controller LE7-40GU-L</td>
<td>Tension controller LE7-40GU-L</td>
</tr>
<tr>
<td>Tension detector LX7-500FN17</td>
<td>Power amplifier LE-50PAU</td>
</tr>
<tr>
<td>Servo motor HG-SR201</td>
<td>Tension detector LX7-500FN17</td>
</tr>
<tr>
<td>Servo amplifier MR-J4-200B</td>
<td>Powder clutch ZKB-40BN</td>
</tr>
<tr>
<td>Geared motor 2.2 kW 1/40</td>
<td>Geared motor 2.2 kW 1/40</td>
</tr>
</tbody>
</table>
Features

- The PLC receives the reel diameter signal from the ultrasonic sensor, and performs external taper control.
- The shaft is changed over during winding using the stop roll.
- The accumulator controls the tension using the powder clutch.

Usage conditions

<table>
<thead>
<tr>
<th></th>
<th>Accumulator</th>
<th>Winding</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tension (N)</td>
<td>20 to 50</td>
<td>20 to 50</td>
</tr>
<tr>
<td>Line speed (m/min)</td>
<td>Max. 75</td>
<td>Max. 75</td>
</tr>
<tr>
<td>Reel diameter (φ)</td>
<td>100</td>
<td>96 to 400</td>
</tr>
</tbody>
</table>

Applicable models

<table>
<thead>
<tr>
<th>Accumulator</th>
<th>Winding</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power amplifier</td>
<td>LE-10WTA-CCL</td>
</tr>
<tr>
<td>Powder clutch</td>
<td>LX-050TD</td>
</tr>
<tr>
<td>Servo motor</td>
<td>HG-SR51</td>
</tr>
<tr>
<td>Servo amplifier</td>
<td>MR-J4-60</td>
</tr>
</tbody>
</table>
The tension detector input adapter LM-10WA-TAD is added to the tension controller LE-10WTA-CCL to control both the winding reel shaft and unwinding reel shaft.

The graphic operation terminal (GOT) is used to set and monitor the tension for winding and tension for unwinding.

### Usage conditions

<table>
<thead>
<tr>
<th></th>
<th>Unwinding</th>
<th>Winding</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tension (N)</td>
<td>44</td>
<td>44</td>
</tr>
<tr>
<td>Line speed (m/min)</td>
<td>30 to 50</td>
<td>30 to 50</td>
</tr>
<tr>
<td>Reel diameter (φ)</td>
<td>60 to 600</td>
<td>60 to 600</td>
</tr>
</tbody>
</table>

### Applicable models

#### Unwinding

- Tension controller: LE-10WTA-CCL + LM-10WA-TAD (including winding)
- Tension detector: LX-015TD
- Power amplifier: LE-50PAU
- Powder brake: ZKB-2.5XN

#### Winding

- Servo amplifier: MR-J4-60
- Servo motor: HG-SR51
Features

- Because there are many roll shafts, the total mechanical loss is large. To reduce the mechanical loss, a powder clutch is installed in each roll shaft to apply driving corresponding to the mechanical loss and eliminate its effect. This system is effective when there are many shafts but low-tension operation is required.

- Many amplifiers are connected through RS-485 communication, and one graphic operation terminal (GOT) sets the parameters of many amplifiers in a batch.

Usage conditions

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Mechanical loss N</td>
<td>1 to 7</td>
</tr>
<tr>
<td>Line speed m/min</td>
<td>0.5 to 5</td>
</tr>
<tr>
<td>Roll diameter φ</td>
<td>250</td>
</tr>
</tbody>
</table>

Applicable models

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Powder clutch</td>
<td>ZKB-1.2BN</td>
</tr>
<tr>
<td>Power amplifier</td>
<td>LD-10PAU-B</td>
</tr>
<tr>
<td>Geared motor</td>
<td>0.75 kW 1/25</td>
</tr>
</tbody>
</table>
Because the hunting phenomenon could occur when the reel shaft is rotating at extremely low (rotation) speed if a servo motor is used, a powder clutch is adopted.

Because the line speed is extremely low, reverse rotation input of the powder clutch is effective in the unwinding section.

Because the distance between rollers is short in the treatment section, draw control is adopted instead of the dancer roll.

### Usage conditions

<table>
<thead>
<tr>
<th></th>
<th>Unwinding</th>
<th>Winding</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tension N</td>
<td>30 to 100</td>
<td>30 to 100</td>
</tr>
<tr>
<td>Line speed m/min</td>
<td>1 to 15</td>
<td>1 to 15</td>
</tr>
<tr>
<td>Reel diameter φ</td>
<td>85 to 400</td>
<td>85 to 400</td>
</tr>
</tbody>
</table>

### Applicable models

#### Shaft A
- Tension controller: LE7-40GU-L
- Tension detector: LX7-150FN17
- Powder clutch: ZA-2.5A (Reverse rotation input)
- Geared motor: 0.2 kW 1/40

#### Shaft B
- Tension controller: LE7-40GU-L
- Tension detector: LX7-150FN17
- Powder clutch: ZA-5A
- Geared motor: 0.4 kW 1/40

#### In-feed area
- Tension detector: LX7-150FN17
- Tension meter: LM-10PD

---

- **Tension meter**
- **Shaft A**
- **Shaft B**
- **Powder clutch**
- **Geared motor**
- **Tension controller**
- **Tension detector**
- **Shaft A**
- **Shaft B**
- **Powder clutch**
- **Geared motor**
- **Tension controller**
- **Tension detector**

---

- **Treatment section**
- **Unwinding Winding**
- **Line speed**
- **Reel diameter**

---

- **Open-loop type tension controller**
- **Shaft A**
- **Shaft B**
- **Powder clutch**
- **Geared motor**
- **Tension detector**
- **Tension controller**

---

- **Features**
  - Because the hunting phenomenon could occur when the reel shaft is rotating at extremely low (rotation) speed if a servo motor is used, a powder clutch is adopted.
  - Because the line speed is extremely low, reverse rotation input of the powder clutch is effective in the unwinding section.
  - Because the distance between rollers is short in the treatment section, draw control is adopted instead of the dancer roll.
• Constant-slip control is adopted in the winding section to mitigate the increase of the powder clutch capacity.
• External taper control is adopted so that the taper ratio can be changed in accordance with the reel diameter.
• Reverse input is adopted on the unwinding side because the line speed may be low.

### Usage conditions

<table>
<thead>
<tr>
<th></th>
<th>Unwinding</th>
<th>Winding</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tension (N)</td>
<td>10 to 50</td>
<td>10 to 50</td>
</tr>
<tr>
<td>Line speed (m/min)</td>
<td>5 to 30</td>
<td>5 to 30</td>
</tr>
<tr>
<td>Reel diameter (φ)</td>
<td>96.2 to 600</td>
<td>96.2 to 600</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Thickness (0.2 to 1.2 mm)</th>
<th>Width (500 to 1200 mm)</th>
<th>Mass (Max. 280 kg)</th>
</tr>
</thead>
</table>

### Applicable models

#### Unwinding
- Tension detector: LX-015TD
- Power amplifier: LE-50PAU
- Powder clutch: ZKB-1.2BN
- Geared motor: 0.2 kW 1/40

#### Winding
- Tension controller: LD-10WTB-CCL + LM-10WA-TAD × 2 units or LE-10-WTA-CCL + LM-10WA-TAD + LD-10WTB-DCA
- Tension detector: LX-015TD
- Power amplifier: LE-50PAU
- Powder clutch: ZA-1.2A
- Constant-torque motor: SF-HRCA-71M
- Inverter: FR-A820-0.4K

---

**Features**

- Constant-slip control is adopted in the winding section to mitigate the increase of the powder clutch capacity.
- External taper control is adopted so that the taper ratio can be changed in accordance with the reel diameter.
- Reverse input is adopted on the unwinding side because the line speed may be low.
Features

- Feedback control is adopted on the unwinding side to improve the torque stability in the low torque region. (Closed-loop control is recommended in areas whose torque is 5% or less in the powder clutch/brake.)

### Usage conditions

<table>
<thead>
<tr>
<th></th>
<th>Unwinding</th>
<th>Unwinding</th>
<th>Winding</th>
<th>Winding</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>AB</td>
<td>C</td>
<td>B</td>
<td>AC</td>
</tr>
<tr>
<td>Tension N</td>
<td>30 to 100</td>
<td>20 to 50</td>
<td>20 to 50</td>
<td>30 to 100</td>
</tr>
<tr>
<td>Line speed m/min</td>
<td>2 to 8</td>
<td>2 to 8</td>
<td>2 to 8</td>
<td>2 to 8</td>
</tr>
<tr>
<td>Reel diameter φ</td>
<td>75 to 450</td>
<td>75 to 250</td>
<td>75 to 250</td>
<td>75 to 450</td>
</tr>
</tbody>
</table>

### Applicable models

<table>
<thead>
<tr>
<th></th>
<th>Unwinding</th>
<th>Winding</th>
</tr>
</thead>
<tbody>
<tr>
<td>AB Unwinding</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tension controller</td>
<td>LE7-40GU-L</td>
<td></td>
</tr>
<tr>
<td>Tension detector</td>
<td>LX7-150FN17</td>
<td></td>
</tr>
<tr>
<td>Powder brake</td>
<td>ZKB-0.6YN</td>
<td></td>
</tr>
<tr>
<td>C Unwinding</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tension controller</td>
<td>LE7-40GU-L</td>
<td></td>
</tr>
<tr>
<td>Tension detector</td>
<td>LX7-150FN17</td>
<td></td>
</tr>
<tr>
<td>Powder brake</td>
<td>ZKB-0.3YN</td>
<td></td>
</tr>
<tr>
<td>B Winding</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tension controller</td>
<td>LD-30FTA</td>
<td></td>
</tr>
<tr>
<td>Tension detector</td>
<td>LX7-150FN17</td>
<td></td>
</tr>
<tr>
<td>Powder clutch</td>
<td>ZKB-0.6AN</td>
<td></td>
</tr>
<tr>
<td>Geared motor</td>
<td>0.2 kW 1/20</td>
<td></td>
</tr>
<tr>
<td>AC Winding</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tension controller</td>
<td>LE7-40GU-L</td>
<td></td>
</tr>
<tr>
<td>Tension detector</td>
<td>LX7-150FN17</td>
<td></td>
</tr>
<tr>
<td>Powder clutch</td>
<td>ZKB-2.5BN</td>
<td></td>
</tr>
<tr>
<td>Geared motor</td>
<td>0.4 kW 1/40</td>
<td></td>
</tr>
</tbody>
</table>
8-20 Film processing machine

**Features**
- Because intermittent operation is performed for pressing the film, an accumulator is installed so that the processing does not stop.
- The forced air cooling type powder clutch is adopted in the winding section to improve heat radiation.

<table>
<thead>
<tr>
<th>Usage conditions</th>
<th>Unwinding</th>
<th>Winding</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tension N</td>
<td>75</td>
<td>75</td>
</tr>
<tr>
<td>Line speed m/min</td>
<td>10 to 40</td>
<td>10 to 40</td>
</tr>
<tr>
<td>Reel diameter φ</td>
<td>90 to 800</td>
<td>90 to 800</td>
</tr>
</tbody>
</table>

**Applicable models**

<table>
<thead>
<tr>
<th></th>
<th>Unwinding</th>
<th>Winding</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tension controller</td>
<td>LE7-40GU-L</td>
<td>Tension controller LE7-40GU-L</td>
</tr>
<tr>
<td>Tension detector</td>
<td>LX-015TD</td>
<td>Tension detector LX-015TD</td>
</tr>
<tr>
<td>Powder brake</td>
<td>ZKB-1.2XN</td>
<td>Powder clutch ZKB-5BN (Forced air cooling)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Geared motor 1.5 kW 1/10</td>
</tr>
<tr>
<td>Section</td>
<td>Title</td>
<td></td>
</tr>
<tr>
<td>---------</td>
<td>-------</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Outline of Tension Control</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Basis of Tension Control</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Torque Control and Speed Control</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Types of Tension Control (Torque Control)</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>What Is a Tension Detector?</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Actuator</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Basis of Tension Control System Construction</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Application Examples</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Trouble Examples and Corrective Actions</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Questions and Answers</td>
<td></td>
</tr>
</tbody>
</table>
Trouble Examples and Corrective Actions
## Trouble Examples and Corrective Actions

<table>
<thead>
<tr>
<th>Phenomenon</th>
<th>Countermeasures</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Clutch /brake</strong></td>
<td>Though the powder clutch/brake is used at the rated or lower torque, its temperature becomes extremely high. The surface temperature becomes 100°C or more. Overload may be applied. The powder clutch/brake may be unavailable even if the used torque does not exceed the rated torque. It is necessary to check the heat dissipation (which is the product of the torque and slip rotation speed) based on the usage conditions. It is necessary to restrict the torque when the slip rotation speed is high. Refer to the catalog for the allowable heat dissipation.</td>
</tr>
<tr>
<td>The powder brake wobbles (does not rotate smoothly) at low speed. This phenomenon often occurs when the reel diameter is large. The stick slip phenomenon may have occurred in the powder brake. The stick slip phenomenon occurs more often when the reel diameter is large (that is, the load is large and the rotation speed is low), and occurs less often as the reel diameter becomes smaller (that is, the load is small and the rotation speed is high). The stick slip phenomenon occurs easily in the unwinding section (powder brake) when the load speed is low (10 m/min. or less). The countermeasure is to increase the slip rotation speed. It is effective to replace the powder brake with the combination of “powder clutch and reverse rotation motor”. Other possible factors on the machine side except the powder brake are the tension of the timing belt and the backlash of the gear. A possible factor on the material side is elongation/shrinkage of the material.</td>
<td></td>
</tr>
<tr>
<td>In the ZA type clutch, the bearing locks early. The idling torque is large. The coil locking bolts may be overtightened. If the coil locking bolts are overtightened on the mounting plate, excessive thrust load is applied to the bearing. When fixing the coil locking bolts on the mounting plate, provide proper backlash in both the axial direction and the rotation direction so that the thrust load is not applied to the bearing.</td>
<td></td>
</tr>
<tr>
<td>Tension controller</td>
<td>The tension is too high at startup in the tension feedback type control. The material breaks off. Turn on/off the input signal in accordance with operation start/stop of the machine. If the input signal is kept ON, the control output becomes largest at the time of restart, and excessive tension is applied. If the input signal is turned off at a delayed timing when the machine is stopped, the control output may become large and excessive tension may be applied at the time of restart. Turn off the input signal at the same time the machine stops.</td>
</tr>
<tr>
<td>The reel becomes loose when the reel diameter becomes small in open-loop control. The looseness may be caused by the nonlinear relationship in the small current region between the current and the torque in the powder clutch/brake. Use the nonlinear correction function of the controller. Though the output voltage change ratio against changes in the reel diameter changes when nonlinear correction is performed, it does not indicate an error. Use the nonlinear correction function of the controller. Though the output voltage change ratio against changes in the reel diameter changes when nonlinear correction is performed, it does not indicate an error.</td>
<td></td>
</tr>
<tr>
<td>The tension increases when the reel diameter becomes small in the unwinding section in automatic control. The increase may be caused by mechanical loss in the winding reel shaft. Check the control output of the controller. When the control output is “0”, the increase is caused by mechanical loss. Major factors of mechanical loss are the bearing, gear, timing belt, etc. of the reel shaft. Mechanical loss tends to be larger with higher gear ratio higher. Reexamination is required, considering countermeasures such as selecting a bearing whose idling torque is small, connecting the reel shaft directly to the elastic coupling without using a gear, decreasing the tension of the timing belt, etc.</td>
<td></td>
</tr>
<tr>
<td>Hunting occurs in the material in feedback control. Check whether hunting occurs in manual operation. If hunting occurs in manual operation, the factors are vibration, mechanical loss fluctuation, etc. in the machine. Check the machine. If hunting does not occur in manual operation but occurs in automatic operation, the control gain may be high. Adjust the control gain.</td>
<td></td>
</tr>
<tr>
<td>Phenomenon</td>
<td>Countermeasures</td>
</tr>
<tr>
<td>------------</td>
<td>----------------</td>
</tr>
</tbody>
</table>
| Tension detector | The deviation may be caused by the effect of mounting the tension detector. Major possible factors are as follows:  
- The detector mounting face is not horizontal.  
- The detector mounting face height is different between both ends when the detection roller is supported at both ends.  
- The detection roller is imbalanced.  
- The detection roller length has changed due to temperature changes. |
| The load becomes excessive during span adjustment though the sum of the roll load and tension load is less than the rated load. | The set value of the tension full scale may be improper.  
- The set value of the tension full scale remains at the default (500 N).  
- The full-scale tension is too high compared with the actual maximum tension to be controlled.  
The recommended full-scale tension is approximately 1.2 to 1.5 times the actually controlled tension. |
Chapter 10

Questions and Answers

10-1 Frequently asked questions about powder clutches and powder brakes
10-2 Frequently asked questions about tension controllers
## 10-1 Frequently asked questions about powder clutches and powder brakes

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| Q19 | What is the idling torque of the powder clutch/brake? | 124 |
Q1: What is the dispersion of the torque in the powder clutch/brake?

A1: In catalogs, the standard torque characteristics (representative example) indicate the standard values of new products at the speed "200 r/min". Because powder deteriorates due to aging, the standard characteristics change accordingly. Cope with changes in the torque characteristics by adjusting the current. The dispersion of the torque at around the rated current is approximately ±10% in a single unit of the product. The dispersion among products is approximately ±15% from the standard torque characteristics. It is recommended to design a system such that the current can be adjusted in each powder clutch/brake when operating multiple powder clutches/brakes in parallel.

![Dispersion of the torque in the product single unit and among products](image)

Q2: How can we judge the end of life (overhaul timing) of the powder clutch/brake?

A2: As the powder clutch/brake is used for a long time, oxidation advances in the powder and the generated torque becomes smaller. As a guideline, consider that the end of life is reached when the torque decreases by 30% or more from the initial value. If it is difficult to measure the torque, judge the end of life based on the "manufactured product finished status" and the fact that "the torque is insufficient even if the speed setting variable resistor is set to the maximum value".

![Rough standard of the life](image)

Q3: Does the power supply unit for the powder clutch/brake have polarity (+ and -)?

A3: The powder clutch/brake uses the DC power supply unit, but it does not have polarity.
Q4: Why is the feeling of the shaft weight dispersed when the shaft is rotated after the powder clutch/brake is connected to the machine?

A4: The shaft feels heavy because the shaft diameter is small and the powder is distributed unevenly before the running-in operation. The dispersion is large because the degree of unevenness of the powder distribution varies among products. Check the feeling of the shaft weight again after performing the running-in operation.

Q5: We would like to use the powder clutch/brake with its shaft set vertical.

A5: Both the powder clutch and the powder brake are designed to be used with the shaft set horizontal in principle. If the powder clutch/brake is used with its shaft set vertical, the powder will not be distributed evenly, the torque will be lower, fluctuate or become uneven, and the original performance cannot be obtained.

Q6: We would like to use the ZKB-40BN with the mounting plate only on one side.

A6: Install the mounting plate on both sides in principle when using the ZKB-5BN or higher models because the shaft load and powder clutch self weight are applied to the mounting area.

Q7: We would like to use the ZKB-10BN as a brake because we do not have the ZKB-10XN.

A7: The ZKB-10BN can be used as a brake when its output shaft is fixed.
Q8: What is the proper water temperature in the water-cooling type?

A8: Supply water of ordinary temperature.
   If the water temperature is low compared with room temperature, condensation may occur due to the difference in temperature.

Q9: What is the allowable surface temperature of the powder clutch/brake?

A9: The table below shows the limit surface temperature allowed in continuous operation.
   If the surface temperature exceeds the value below, the durability will be considerably deteriorated.

<table>
<thead>
<tr>
<th>Model</th>
<th>Limit temperature (Rough standard)</th>
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<tr>
<td>Natural cooling</td>
<td>100°C or less</td>
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<td>Thermo block</td>
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<td>Water-cooling type ZKB-WN</td>
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<td>Forced cooling</td>
<td>70°C or less</td>
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<tr>
<td>Compressor</td>
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</table>

Q10: We would like to use the powder clutch/brake outdoors.

A10: The powder clutch/brake is designed to be used inside a factory, and cannot be used outdoors in principle.
   If using the powder clutch/brake outdoors, create an environment similar to an indoor environment by attaching a cover if the powder clutch/brake will be exposed to water drops, oil drops, sand dust, salty air, etc. In addition, prevent condensation.
Q11: We would like to use the powder clutch/brake in a vacuum.

A11: It is not possible to use the powder clutch/brake in a vacuum because the slip heat cannot be radiated to the air and the allowable heat dissipation is extremely low.

Q12: We would like to use the powder clutch/brake in a clean room.

A12: It is not possible to use the powder clutch/brake in a clean room in principle because it does not have a completely sealed structure and fine powder generated during use may leak. When covering the powder clutch/brake, cover the entire moving parts because dust is generally generated from other moving parts such as the gear and belt.

Q13: What is the upper limit of use of the powder clutch/brake?

A13: The rated torque is the upper limit. Though the powder clutch/brake is designed to produce a higher torque than the rated torque when shipped from the factory in view of deterioration due to aging, the powder clutch/brake is not guaranteed if it is used above the rated torque.

Q14: Is the rotation direction specified for the powder clutch/brake?

A14: The powder clutch/brake can rotate in either direction because rotation does not have directionality.
Q15: Please explain the life of the powder clutch/brake.

A15: Powder is oxidized when the powder clutch/brake is used for a long time, and the torque decreases due to the oxidation. When the powder clutch/brake is used for winding or unwinding with the allowable heat dissipation, the life of powder is generally 5,000 to 8,000 hours.

This value is determined assuming that the powder reaches its end of life when the torque decreases until the rated value at the rated current. The life is longer if the powder clutch/brake is used at a torque lower than the rated torque because powder can be used continuously.

As a guideline, consider that the powder has reached its end of life and the powder clutch/brake requires overhaul when the torque decreases by 30% or more from the initial value.

If it is difficult to measure the torque, judge the end of life based on the "manufactured product finished status" and the fact that "the torque is insufficient even if the speed setting variable resistor is set to the maximum value".

The powder life can be extended if the powder clutch/brake is used with sufficient margin from the allowable heat dissipation. For example, if the powder clutch/brake is used with the heat dissipation at 50% of the allowable value, the powder life may be twice or more.

On the contrary, if the powder clutch/brake is used with the heat dissipation above the allowable value, the oxidation of powder may worsen drastically, the decrease of torque may be accelerated, and parts may be damaged.

Even when the heat dissipation is the same, the powder life tends to be short if the slip rotation speed is continuously high. Set the system so that the slip rotation speed becomes as low as possible.

Q16: Which is the input/output shaft of the powder clutch?

A16: "IN (input side)" and "OUT (output side)" are indicated on the product nameplate.

The nameplate attached on the outer periphery of the product indicates the information required to control the product.
Q17: Which of the input shaft and the output shaft of the powder clutch should be connected to the high-speed rotation side?

A17: Connect the input side (IN) to the high-speed rotation side, and connect the output side (OUT) to the low-speed rotation side. Connecting the input side (IN) to the high-speed rotation side leads to stable torque and long powder life.

Powder is filled between two rotating bodies. When each rotating body is rotated individually, powder moves as follows:

- When the input side is rotated
  - Powder receives the centrifugal force from the input side, adheres on the inner circumference on the input side, and is distributed stably.
  - When the output side is rotated
  - Powder receives the centrifugal force from the output side, and scatters from the output side.

Because powder is always moving, it is distributed unevenly.

Q18: Please explain how to install the ZKG-AN type powder clutch.

A18: The ZKG-AN type powder clutch should be handled carefully because its input shaft and output shaft are different from those of other types.

In the ZKG-AN, outputs are provided on the left and right sides. Select either one in accordance with the equipment to be combined.

Target models:
ZKG-5AN, ZKG-10AN, ZKG-20AN and ZKG-50AN

Q19: What is the idling torque of the powder clutch/brake?

A19: The idling torque refers to the drag torque which is generated by powder, bearings, etc., and is generated even while the power is OFF.

The idling torque is 1 to 10% of the rated torque. The actual value varies depending on the model. Refer to the corresponding manual and catalog for details.

Because the powder clutch/brake cannot output a torque smaller than the idling torque, consider the idling torque also when selecting a powder clutch/brake to be used.
### 10-2 Frequently asked questions about tension controllers

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| Q6 | What is a hinge of the tension detector? | 128 |
| Q7 | Why is the tension detector not displaced even when a load is applied? | 128 |
| Q8 | Why do torque fluctuations and hunting occur (especially in the low torque region)? | 129 |
| Q9 | Why does the tension not increase immediately after the line driving is started in winding control using the powder clutch? | 129 |
| Q10 | Why does the tension increase as the reel diameter becomes smaller on the unwinding side in closed-loop tension control? | 130 |
| Q11 | Why does the tension easily decrease when the reel diameter is small in open-loop control? | 130 |
Q1: Is it possible to use the existing power supply unit even if the powder clutch/brake model is changed?

A1: The existing power supply unit can be used when the rated current of the newly adopted powder clutch/brake is smaller than the current capacity of the power supply unit.

Q2: What will happen if the output terminals are short-circuited in the controller and manual power supply unit?

A2: The short-circuit protection circuit operates. Release the short-circuit area, turn off the power, wait for 30 seconds, and then turn on the power again to recover the system.
Q3: Can one power supply unit be used for multiple powder clutches/brakes?

A3: One power supply unit can be used for multiple powder clutches/brakes provided the rated current of the powder clutch/brake multiplied by the number of powder clutches/brakes does not exceed the current capacity of the power supply unit. However, the torque may be different among the powder clutches/brakes used together even if the output is the same because the performance is not equivalent among powder clutches/brakes.

Q4: We would like to indicate the tension while using the manual power supply unit or open-loop type controller.

A4: The manual power supply unit and open-loop type controller cannot indicate the tension. A tension detector and tension meter are required separately in order to indicate the tension.
Q5: The length of the cable (7 m in the non-explosion-proof specifications, 20 m in the explosion-proof specifications) supplied as an accessory of the tension detector is insufficient. Can it be extended?

A5: An optional extension cable (50 m) is available. Contact your sales agent.

Q6: What is a hinge of the tension detector?

A6: A flat spring supported on only one side is incorporated in the tension detector, and its bend is detected. The supporting point of the flat spring is called a hinge. If the resultant force of the tension faces the hinge direction, the flat spring bends by less than the degree corresponding to the actual tension, and the accuracy of tension detection is poor. This should be considered when selecting the tension detector.

Q7: Why is the tension detector not displaced even when a load is applied?

A7: The pillow block mounting bolts may be interfering with the housing. As a countermeasure, use shorter bolts to prevent interference.
Q8: Why do torque fluctuations and hunting occur (especially in the low torque region)?

A8: The mechanical loss may have some effect.
   As a countermeasure, it is necessary to reduce the mechanical loss.
   Major causes of mechanical loss are the sliding resistance of the bearing which supports the reel shaft and the gear installed between the reel shaft and the brake.
   The mechanical loss tends to increase with higher gear ratio.
   Because the mechanical loss is not constant but fluctuates, it may cause tension fluctuations and hunting.
   Hunting can occur easily in the low torque region (where the output voltage is low) because the reel shaft torque is affected considerably by the torque caused by the mechanical loss.

Q9: Why does the tension not increase immediately after the line driving is started in winding control using the powder clutch?

A9: The material may have been slack when the machine was stopped.
   As a countermeasure, drive the winding motor in advance before driving the machine main motor so that the material is not slack when the tension controller is started.
Q10: Why does the tension increase as the reel diameter becomes smaller on the unwinding side in closed-loop tension control?

A10: The mechanical loss may have some effect. The mechanical loss is regarded as the cause when the voltage applied to the powder brake is “0”. As a countermeasure, it is necessary to reduce the mechanical loss. Major causes of mechanical loss are the sliding resistance of the bearing which supports the reel shaft and the gear installed between the reel shaft and the brake. The mechanical loss tends to increase with higher gear ratio.

Q11: Why does the tension easily decrease when the reel diameter is small in open-loop control?

A11: The powder characteristics (nonlinear in the low torque region) may have some effect. As a countermeasure, use the powder nonlinearity correction function which improves the torque characteristics in the low current region.
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