FA_Equipment_for_Beginners(Positioning)_ENG

MITSUBISHI ELECTRIC
Changes for the Better

FA Equipment for Beginners (Positioning)

This is a quick overview of Positioning control for beginners.

Introduction Purpose of the Course

Positioning control enables high speed, accurate and precise object transfer to a destination.
This course is intended to equip beginners with the basic knowledge required before performing actual positioning control.

Introduction Course Structure

The contents of this course are as follows.
We recommend that you start from Chapter 1.

Chapter 1 - Learning the Basics of Positioning Control

Learn the basics of positioning control.

Chapter 2 - Components Required for Positioning Control

To learn about the component equipments required for positioning control and their roles

Chapter 3 - How to Control Positioning

To learn about design methodology of positioning control

Chapter 4 - What to Consider in Actual Positioning

To learn about other factors to be considered for actual positioning control

Final Test

Passing grade: 60% or higher.

Introduction How to use this e-Learning Tool

Go to the next page		Go to the next page.
Back to the previous page		Back to the previous page.
Move to the desired page	TOC	"Table of Contents" will be displayed, enabling you to navigate to the desired page.
Exit the learning		Exit the learning. Window such as "Contents" screen and the learning will be closed.

Precautions for Use

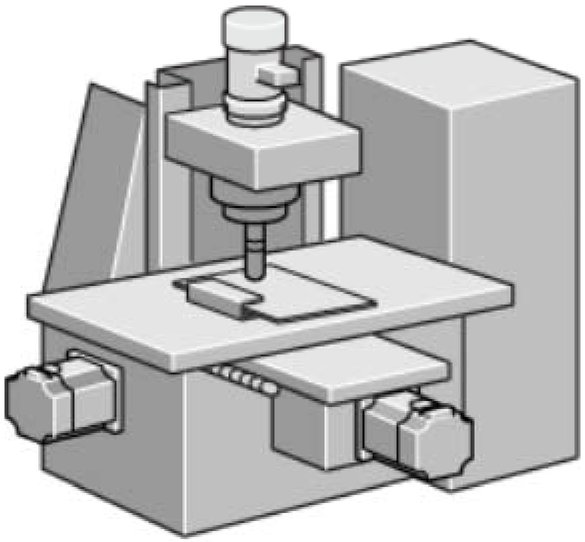
Safety precautions

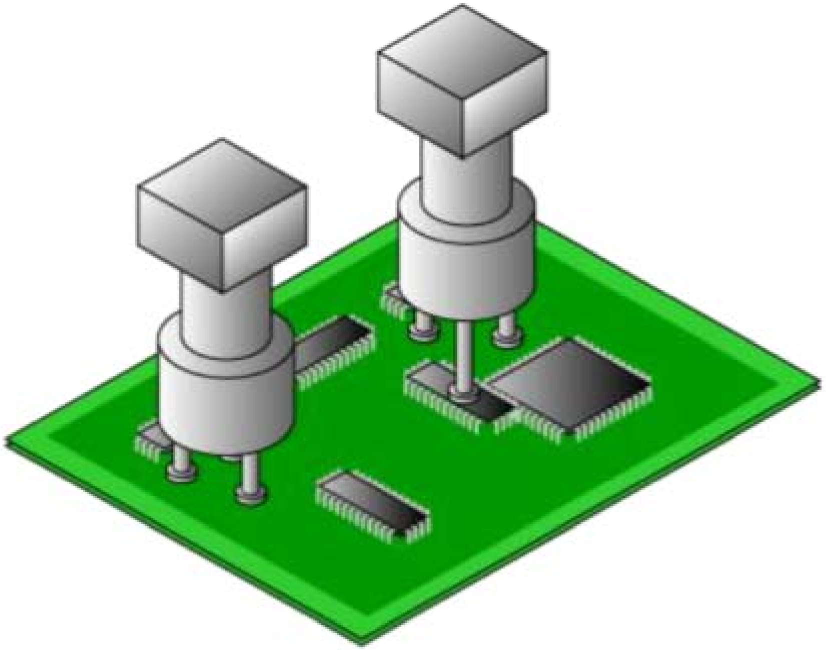
Before using the physical hardware please read the Safety Precautions in the corresponding manuals and follow the relevant safety information contained therein.

Chapter 1 Why Positioning Control?

The Demand for Positioning Control

The advancement of machining and assembly technology has pushed the precision and efficiency limits of industrial products.
Therefore, the demand for positioning control is becoming more significant.

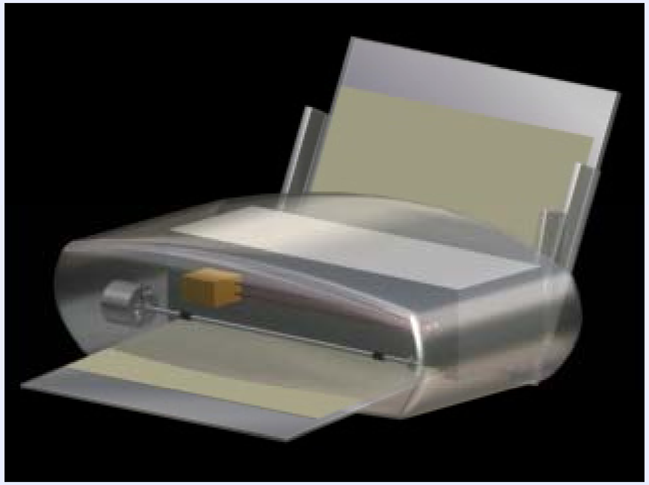




1.1 Example of Positioning Control

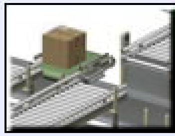
A common example of positioning control is the inkjet printer.
Accurate movement of the print head and paper feed are necessary for high resolution printing.
In FA, positioning control is also used for luggage transport system.

Click the following thumbnails to play the video of the respective examples.



Common example 1
Head of inkjet printer

Common example 2
Paper feed of inkjet printer

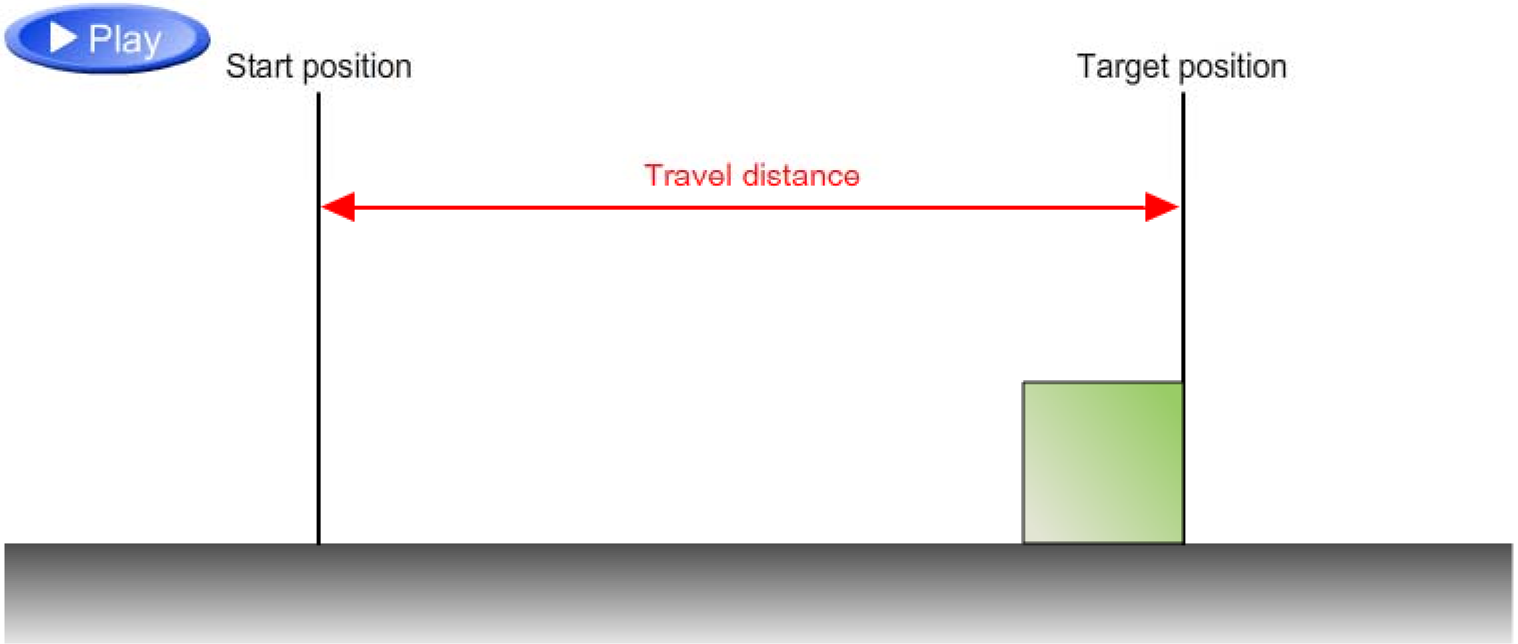


FA example 1
Luggage transport system

1.2.1 What is Positioning Control?

Positioning control refers to controlling an object so that it moves from the start position to the target position and stops there precisely.

Press the "Play" button below to see the action of positioning control.

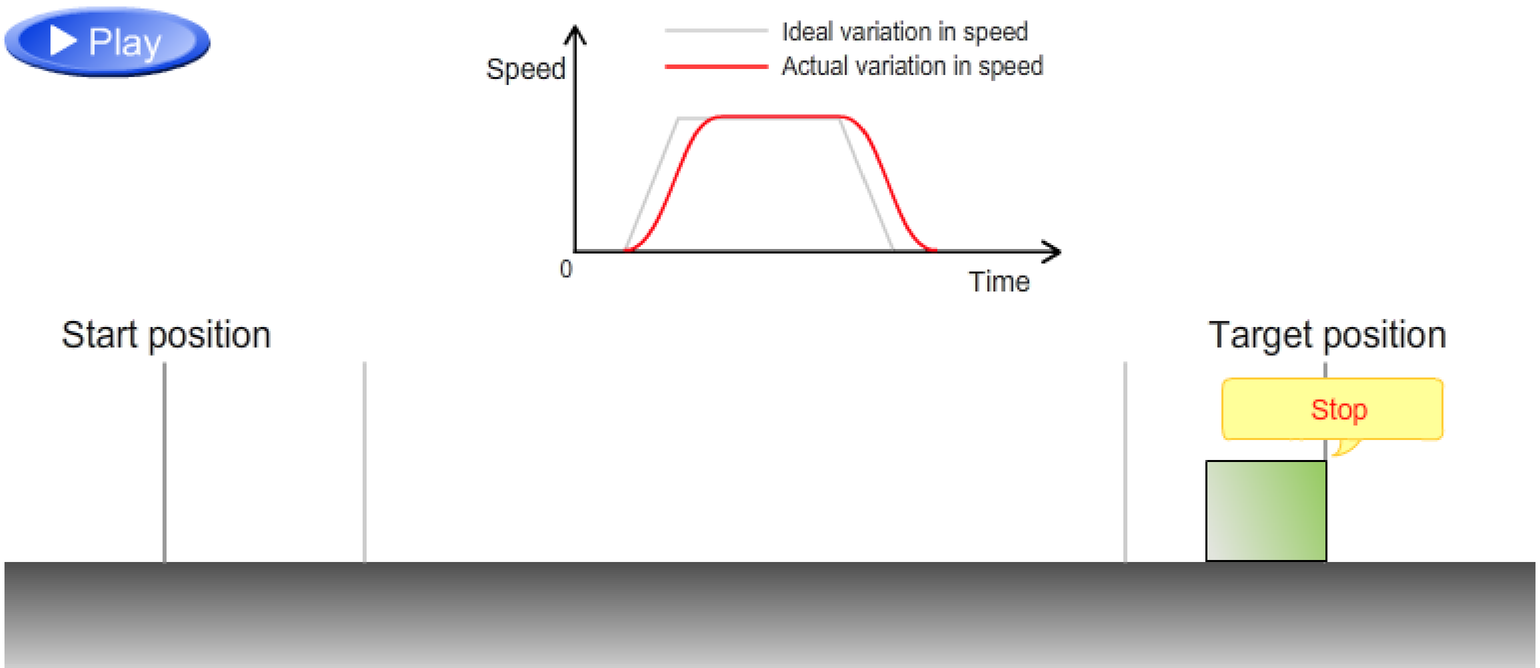


1.2.2 Optimal Positioning Control

To improve the transfer efficiency when moving an object, it is necessary to move it as quickly as possible.
However, the drive unit (such as a motor) and object are affected by inertia and friction. A sudden acceleration or deceleration could jerk the object or overrun the target position.
To avoid these problems, smooth acceleration and deceleration are required.

The following figure shows the transfer of an object to the target position through "acceleration," "constant speed," and "deceleration."
The graph shows the ideal and actual variations in speed of the object.
This type of movement can move the object quickly and accurately.

Press the "Play" button in the following figure to see the positioning by smooth acceleration and deceleration.

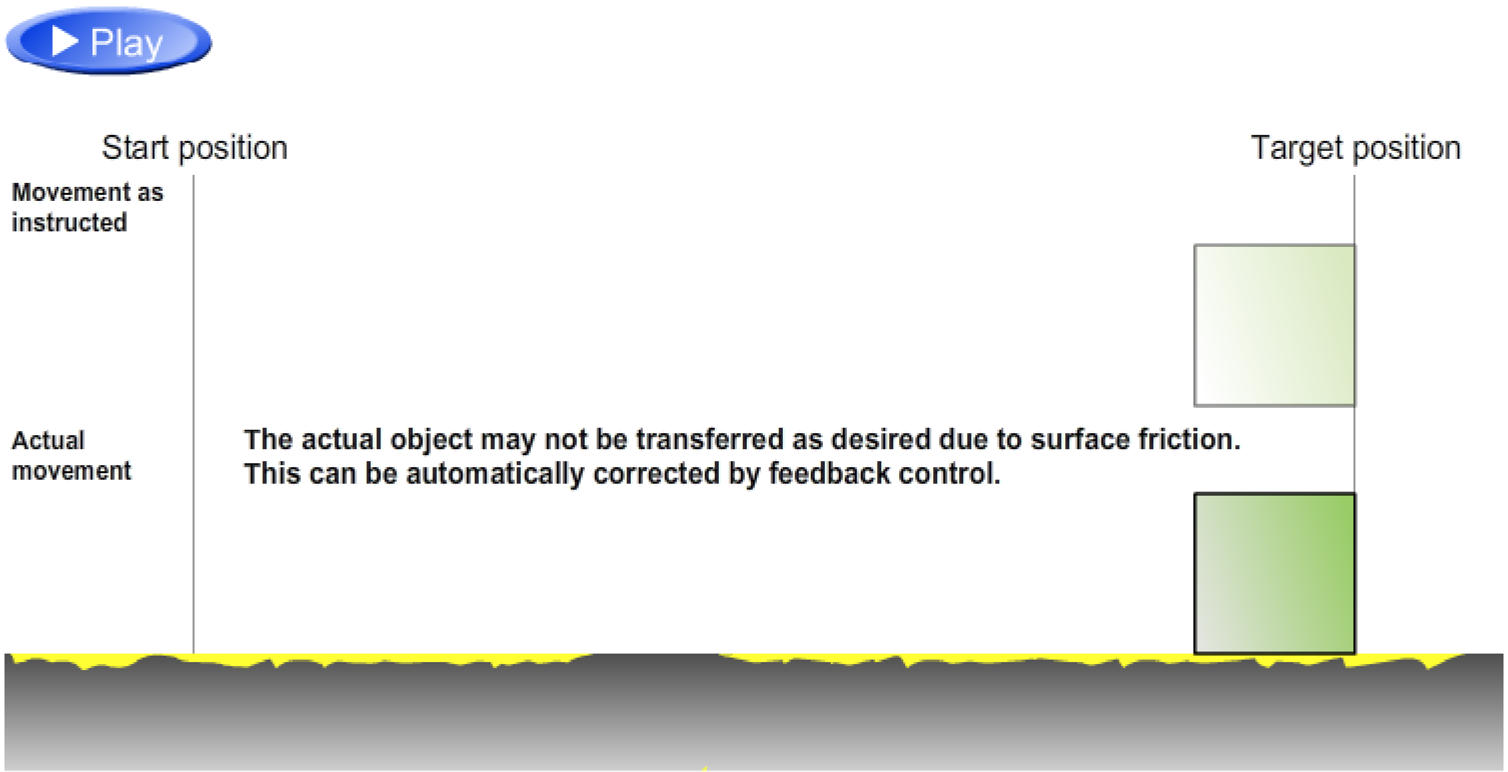


1.2.3 Accurate Positioning

To allow the object to leave the start position and reach the target position accurately, it must be moved while always comparing the current position with the specified position, and adjusting the speed to correct the current position.

The monitor and correction throughout the positioning process is called "feedback control".

Press the "Play" button in the following figure to see the role of feedback control.

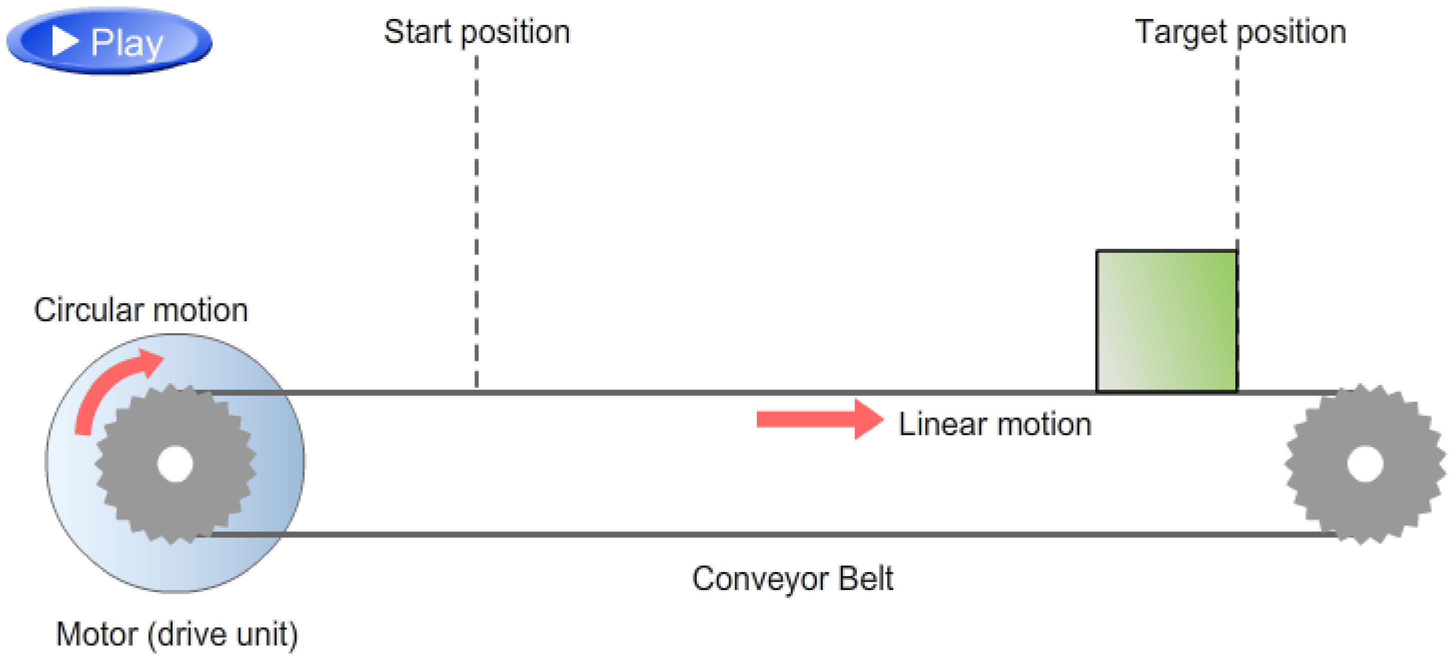


1.2.4 Converting Circular Motion to Linear Motion

The basic operation of positioning control is linear movement from the start position to the target position.

A highly efficient easy-to-control motor is often used for the drive unit for linear motion.
As the motor operation is circular motion (rotary motion), a belt conveyor is used to convert the circular motion to linear motion as shown in the figure below.

Press the "Play" button in the figure below to see the conversion from circular motion to linear motion.

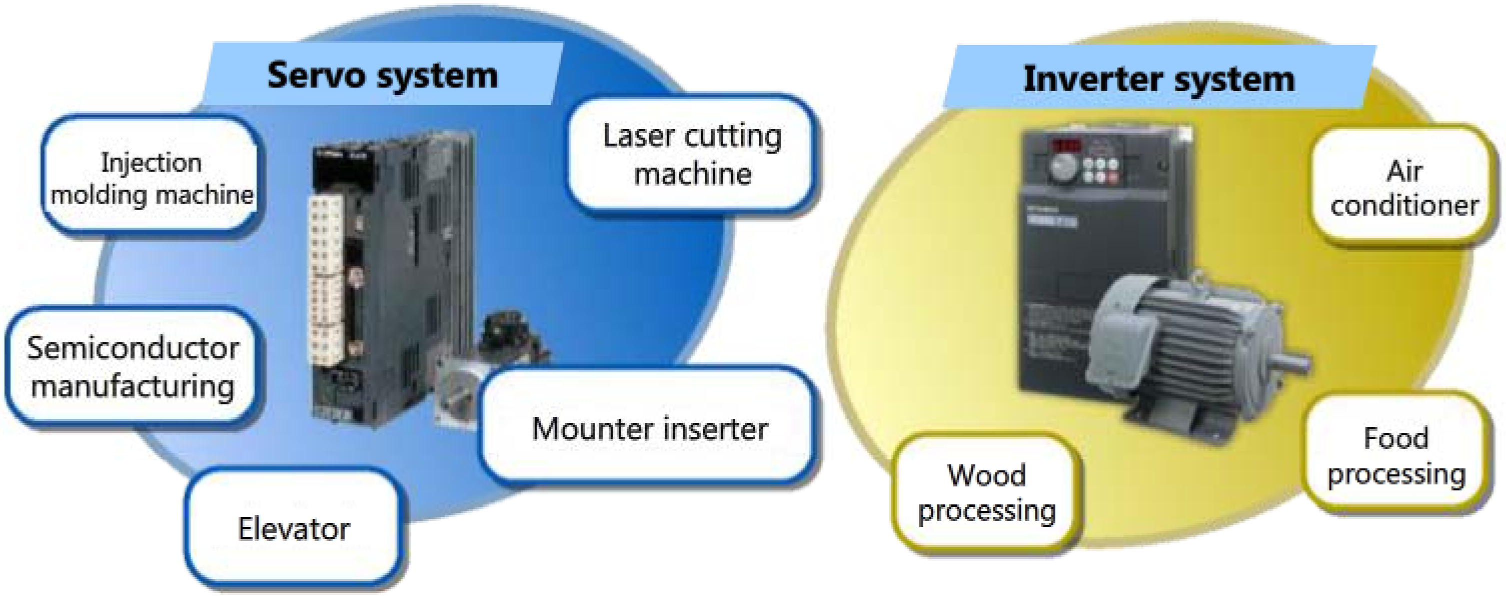


1.3 Advantages of Using Servo System for Positioning Control

Two main control systems are used for control with a motor: a servo system and an inverter system.

Let's check where the servo system and inverter system are used.
As shown in the following examples, the inverter system is used to control speed.
The servo system is suitable for positioning control.

Examples of servo system and inverter system



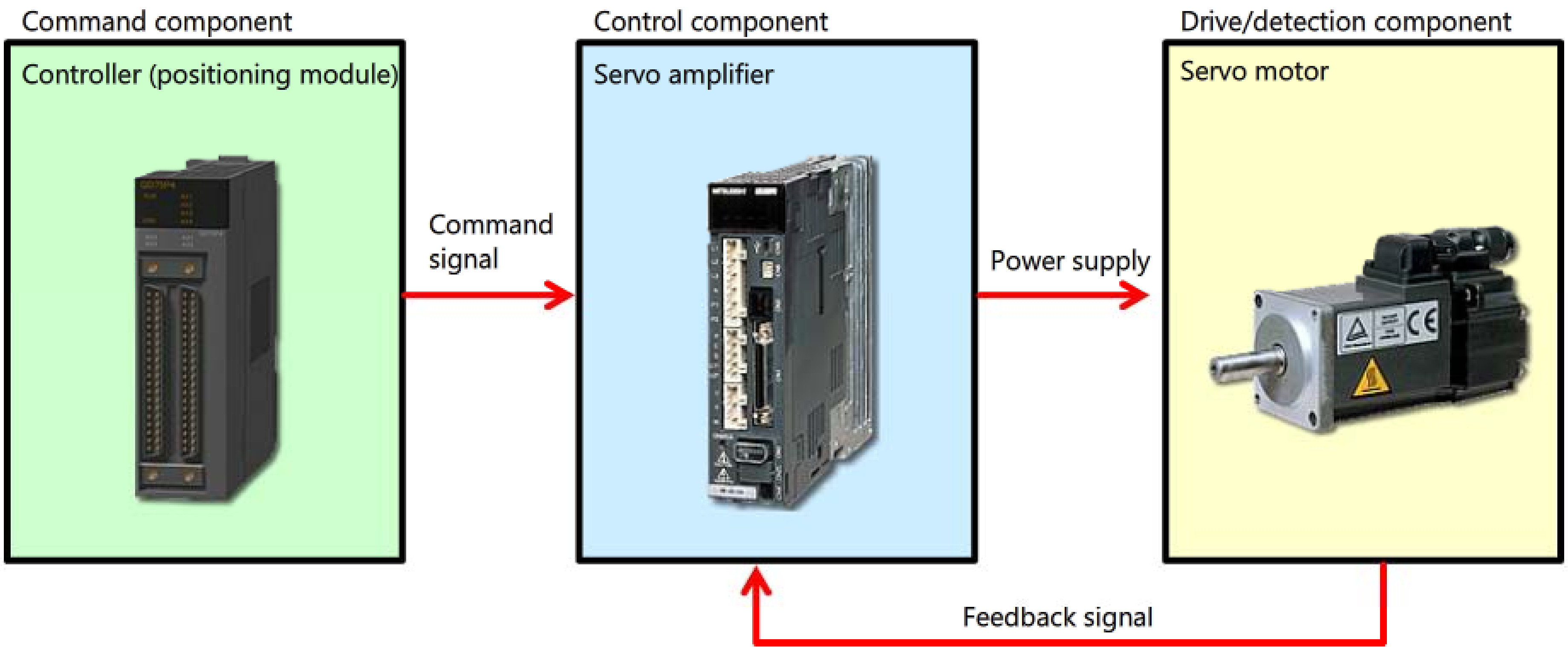
Chapter 2 Components Needed for Positioning Control

In this chapter, you are going to learn about the components required for positioning control using the servo system and the roles of individual components.

Positioning control is composed of three components: command component, control component, and drive/detection component.

The following figure shows an equipment configuration using a controller (positioning module) in the command section, a servo amplifier in the control section, and a servo motor in the drive/detection section.

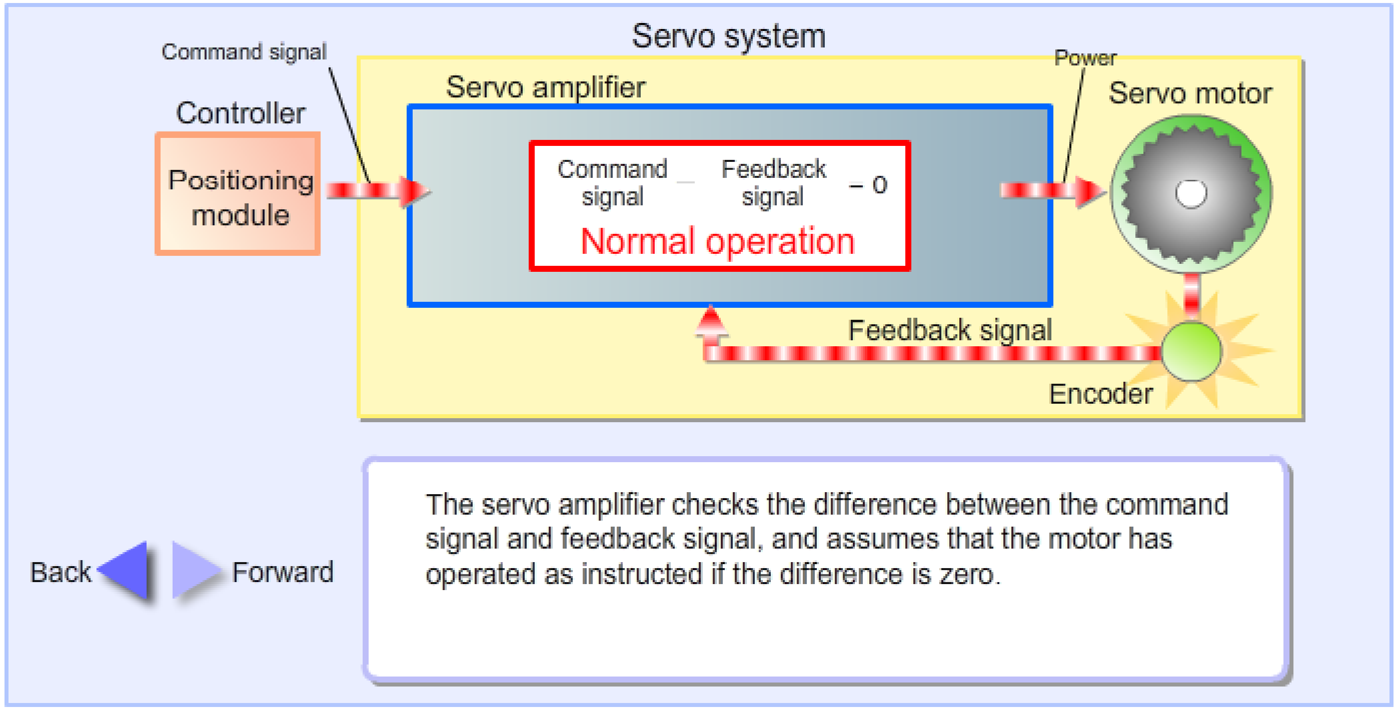
Equipment Configuration for Positioning Control



2.1 Flow of Positioning Control

Here, you will learn about the flow of a control signal between equipment components.

Press the "Forward" button in the figure below to see the flow of positioning control.
(Pressing the "Back" button returns to the previous explanation.)

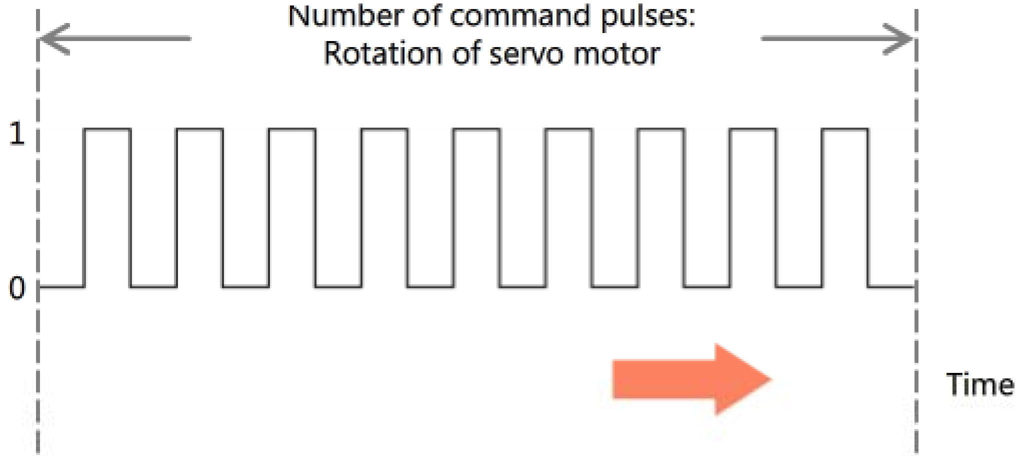


The servo amplifier checks the difference between the command signal and feedback signal, and assumes that the motor has operated as instructed if the difference is zero.

2.2.1 Role of the Positioning Module

To transfer an object, the positioning module generates and sends a command signal to the servo amplifier.
In positioning control, pulse signals are used as command signals and are called command pulses.
The servo motor rotates by the number of command pulses sent from the positioning module to the servo amplifier.
The number of command pulses per unit time is called the command pulse frequency and is used to control the speed of the servo motor.

The following figure shows the number of command pulses and the command pulse frequency.



Number of command pulses per unit time:
Speed of servo motor = Command pulse frequency [pulses/sec]

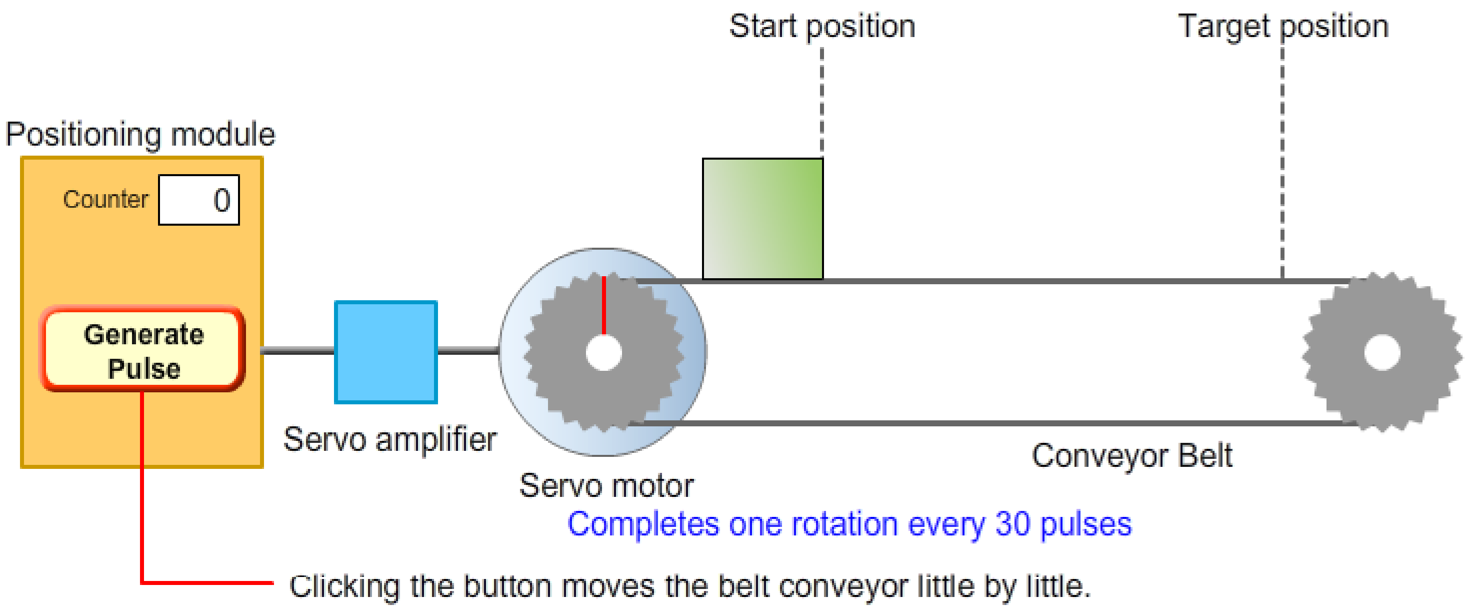
2.2.2 Roles of the Number of Command Pulses and Command Pulse Frequency

Here, you will learn the roles of the number of command pulses and the command pulse frequency, and the relationship between their roles and the object (work*).

The figure below shows a belt conveyor using a servo motor that completes one rotation every 30 pulses.
Pressing the button on the positioning module once generates one pulse.
One pulse rotates the servo motor 12 degrees and the work on the belt conveyor moves toward the target position.
The number of times the button is pressed (counter value) is the number of command pulses, and the interval at which the button is pressed is the command pulse frequency.

* In positioning control, the target object to be positioned is called a "work."

Press the "Generate Pulse" button on the positioning module in the figure below to see the relationship between the number of command pulses/command pulse frequency and work.



2.3.1 Role of the Servo Motor

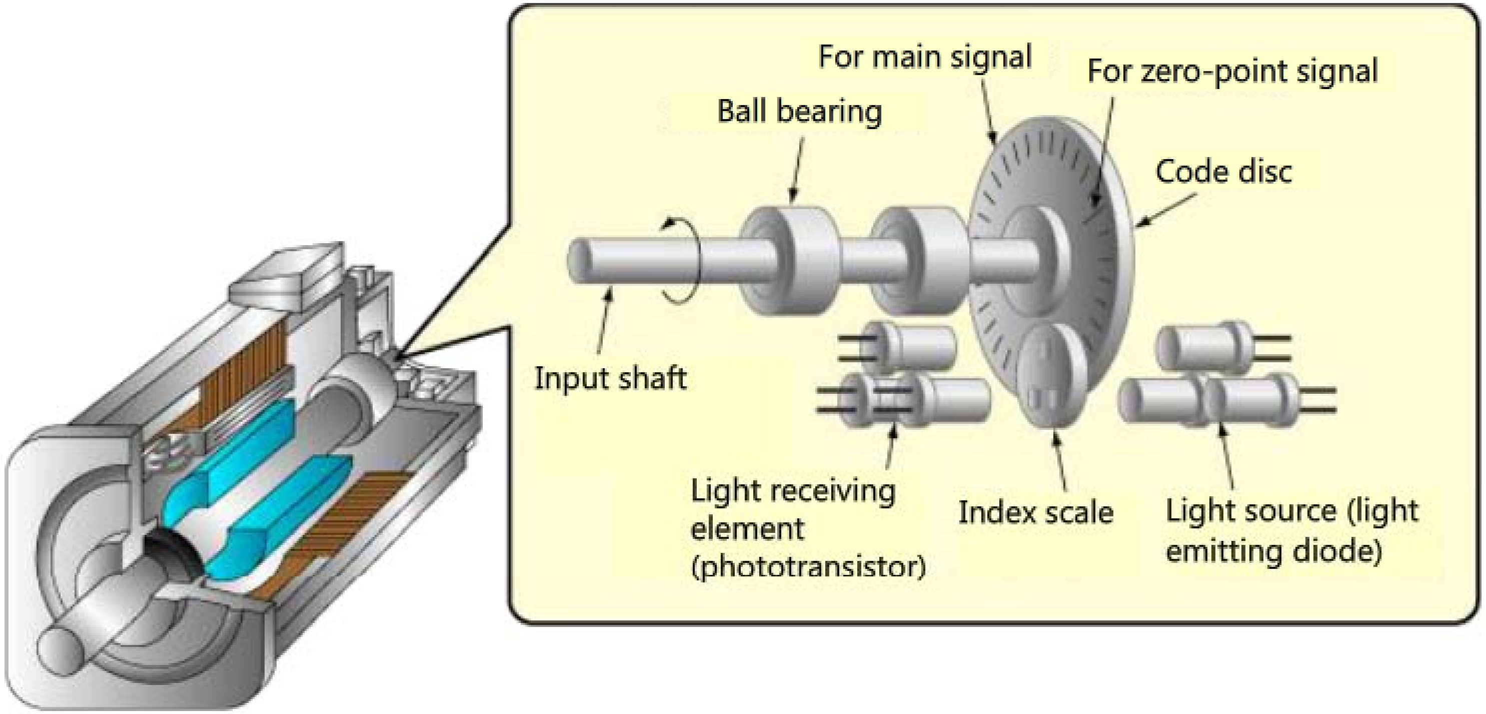
The servo motor moves the work by rotating faithfully following the power supplied by the servo amplifier.
The servo motor has a built-in detector (encoder) that can accurately count the rotation speed and how many times the motor has rotated.
In actual positioning, the mechanism may not work as instructed due to machine characteristics and disturbances.
To avoid this problem, a feedback mechanism using an encoder is required.

Rated rotation speed

The speed at which the servo motor rotates most efficiently is called the "rated rotation speed."
Setting the speed for constant operation to the rated rotation speed [r/min] of the servo motor enables efficient positioning operation.

Mechanism of the encoder

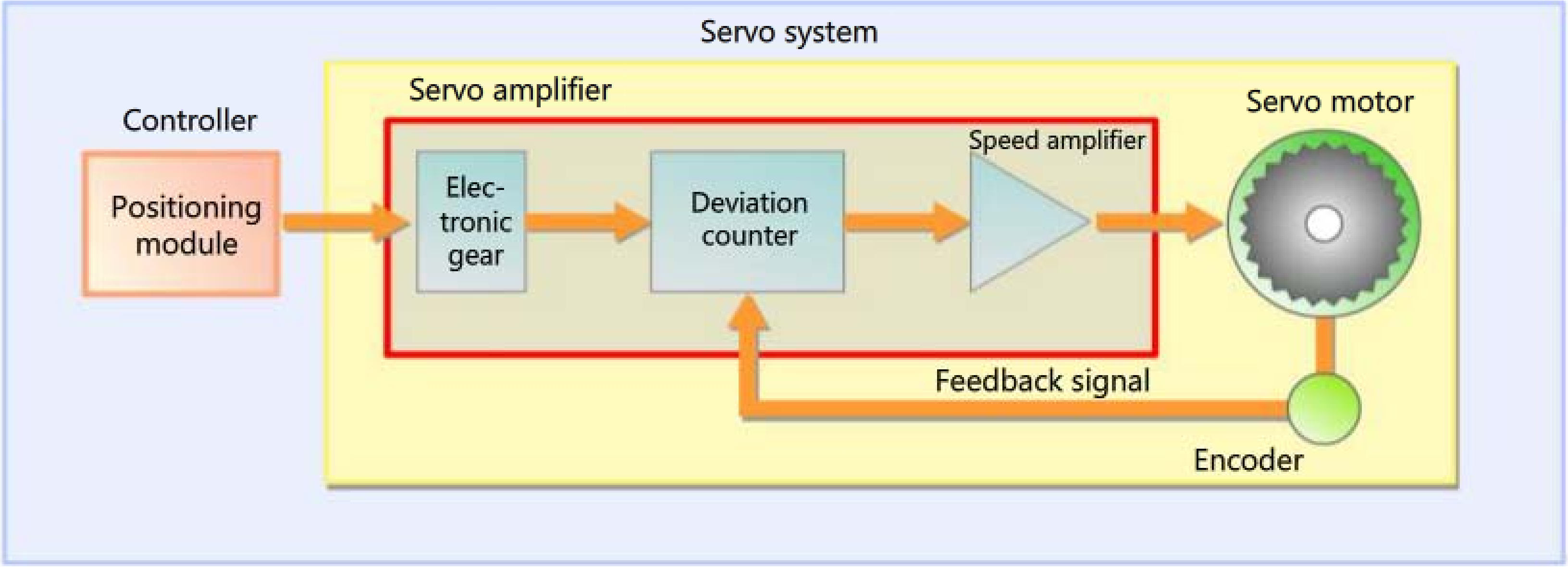
Light is shined on a rotating disc with evenly spaced slits near its circumference.
An encoder placed behind the disc counts each time the light shines through a slit.
The counted amount is fed back to the servo amplifier to enable accurate positioning control.
The higher the encoder resolution [pulses/rev] of the servo motor, the more accurate the positioning.



2.4 Role of the Servo Amplifier

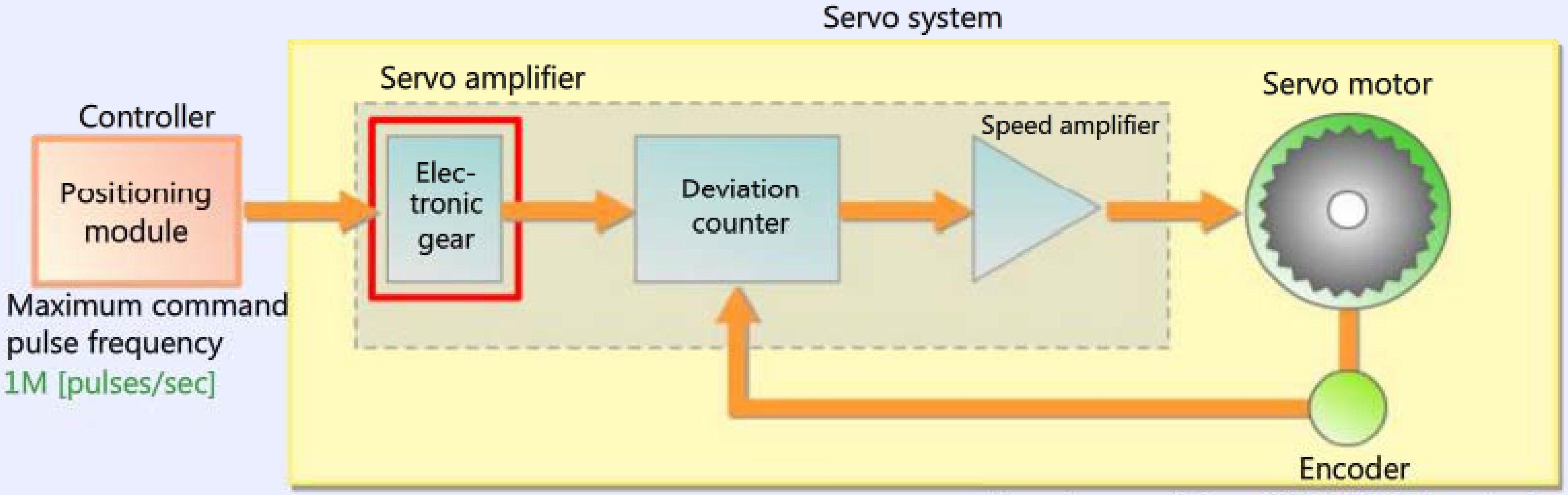
The servo amplifier controls the servo motor as instructed by the command signal from the positioning module.
The servo amplifier also uses the feedback signal from the encoder to keep checking whether the servo motor is operating as instructed (for errors) and to correct any errors as needed.

Here, you will learn about the "electronic gear," "deviation counter," and "speed amplifier" of the servo amplifier.



2.4.1 Role of the Electronic Gear

The servo motor operates most efficiently at the rated rotation speed. However, the maximum command pulse frequency that can be output by the positioning module is fixed and, if this value is too low, it cannot output sufficient commands for the motor to reach the rated rotation speed. To solve this problem, an electronic gear is provided to increase the command pulse frequency.



Encoder resolution: 262,144 [pulses/rev]
Rated rotation speed: 3,000 [rpm]
Maximum rotation speed: 6,000 [rpm]

Example: When no gear is used (x), the maximum speed of the servo motor is 1,000,000 x 1/262,144 x 60 = 229 [rpm]

Electronic gear magnification	Maximum speed of servo motor [rpm]	
1x (without gear)	229	The rated rotation speed is not reached and the performance of the servo motor cannot be achieved.
2x	458	
10x	2,290	
20x	4,580	The rated rotation speed is reached and the performance of the servo motor can be achieved.

Under this condition, the electronic gear ratio should be fixed to around 20x to convert the command pulse frequency to control the motor speed.

2.4.1 Role of the Electronic Gear

Determining the electronic gear ratio

Command pulse frequency ≧ servo motor rotation speed

↓

Maximum command pulse frequency x electronic gear ratio ≧ resolution x rated rotation speed

Set the electronic gear ratio so it satisfies the above.

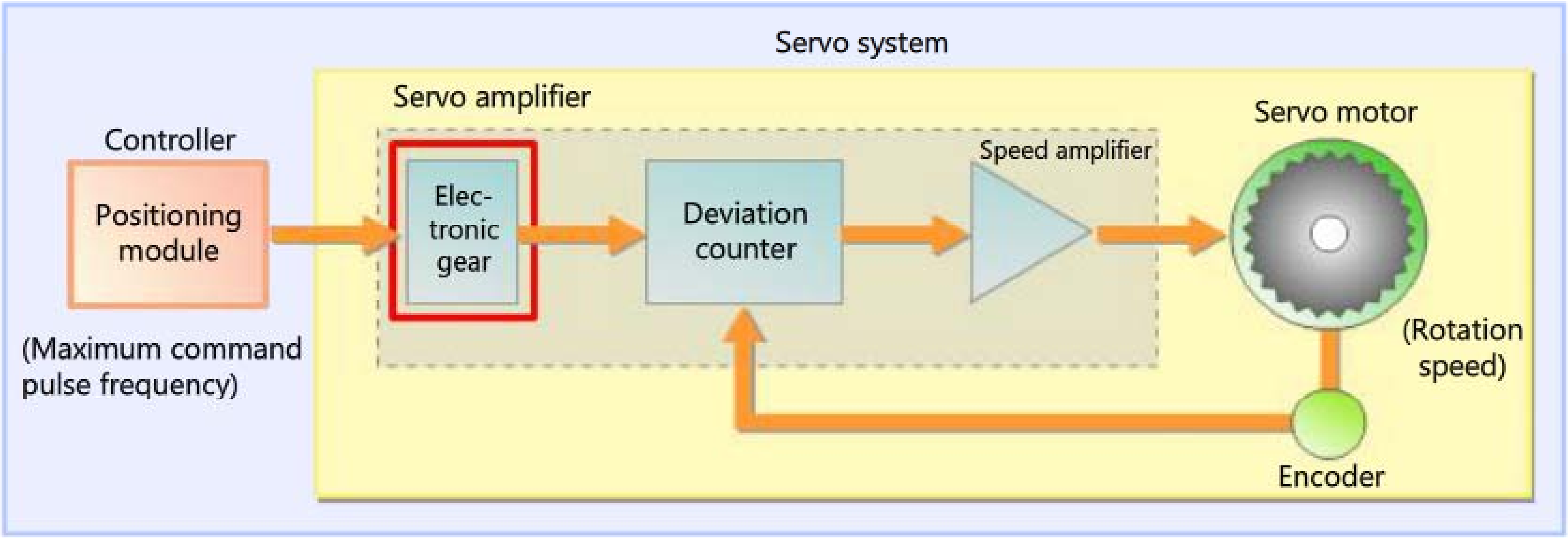
Example: In the case of the following:

Command pulse frequency: 200k [pulses/sec]
Resolution: 16,384 [pulses/rev]
Rated rotation speed: 2,400 [rpm]
(2,400 [rpm] = 40 [r/sec])

200k [pulses/sec] x Electronic gear ratio ≧ 16,384 [pulses/rev] x 40 [r/sec]

$$\text{Electronic gear ratio} \geqq \frac{16{,}384\ [\text{pulse/rev}] \times 40\ [\text{r/sec}]}{200\text{k}\ [\text{pulses/sec}]}$$

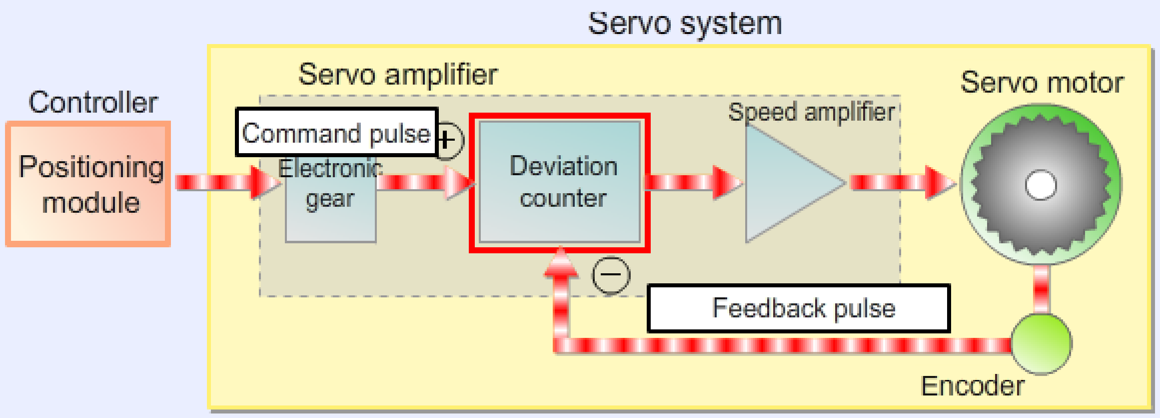
is obtained.



2.4.2 Role of the Deviation Counter

The deviation counter subtracts the encoder's feedback pulses from the positioning module's command pulses.
The resultant pulses accumulated in the deviation counter are called the error pulses.
The deviation counter outputs a speed command proportional to the error pulse value to the speed amplifier.
When the number of error pulse is large, the rotation speed of the servo motor is accelerated. As it becomes smaller, the speed is decelerated and stopped when the value is zero.
The following figure explains the role of the deviation counter.

Press the "Forward" button in the figure below to see the role of the deviation counter.
(Pressing the "Back" button returns to the previous explanation.)



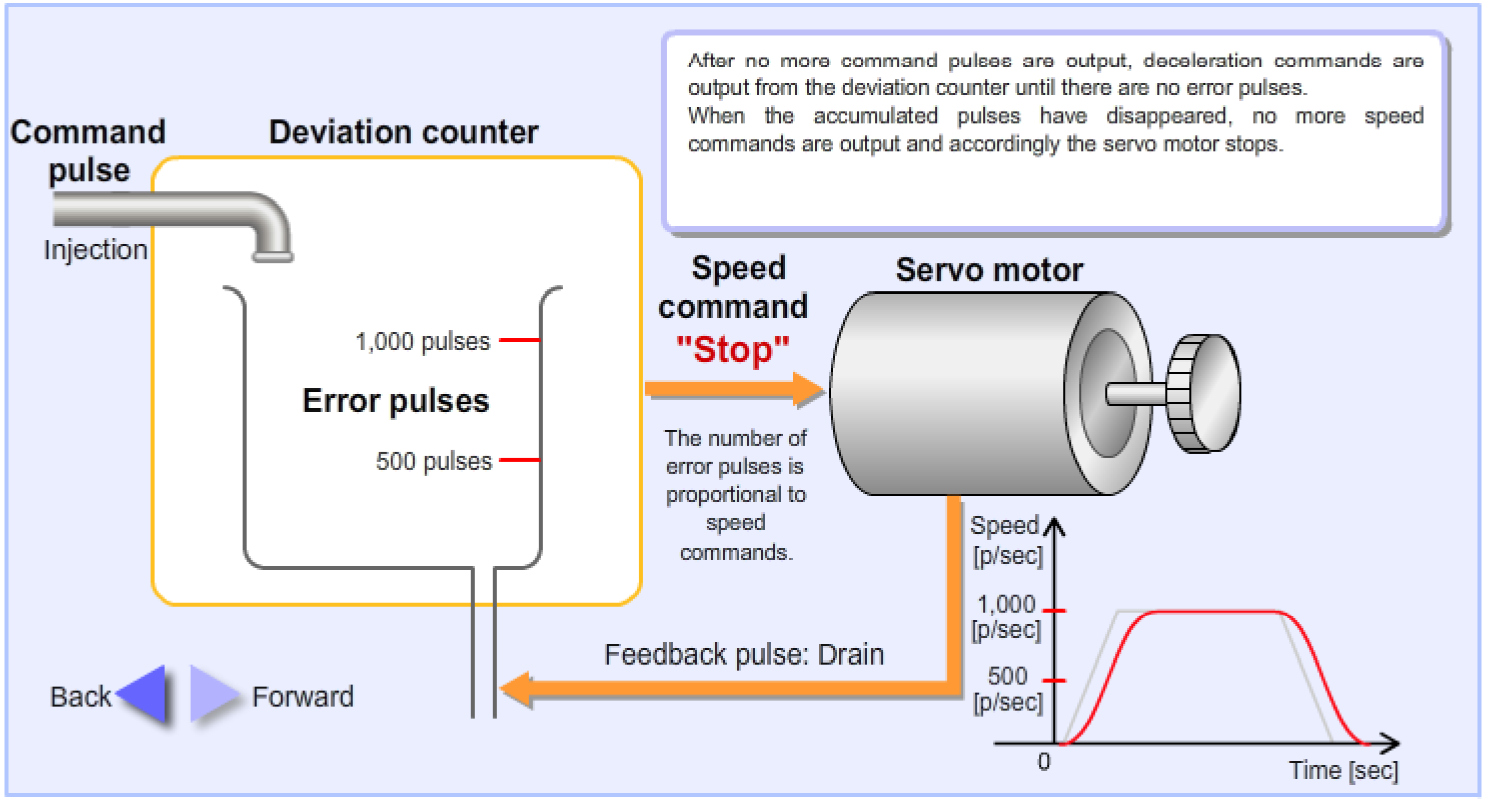
Back Forward

A speed command proportional to the error pulse value, which is the difference between command pulses and feedback pulses, is output to the speed amplifier to control the servo motor.

2.4.3 Feedback Mechanism

The servo system has a feedback mechanism to ensure accurate, smooth, and high-speed positioning.
The feedback mechanism essentially generates error pulses, which are the difference (delay) between command pulses and feedback pulses.
The following figure explains the feedback mechanism.

Press the "Forward" button in the figure below to see the feedback mechanism.
(Pressing the "Back" button returns to the previous explanation.)



2.4.3 Feedback Mechanism

Adjusting the Responses from the Feedback Mechanism

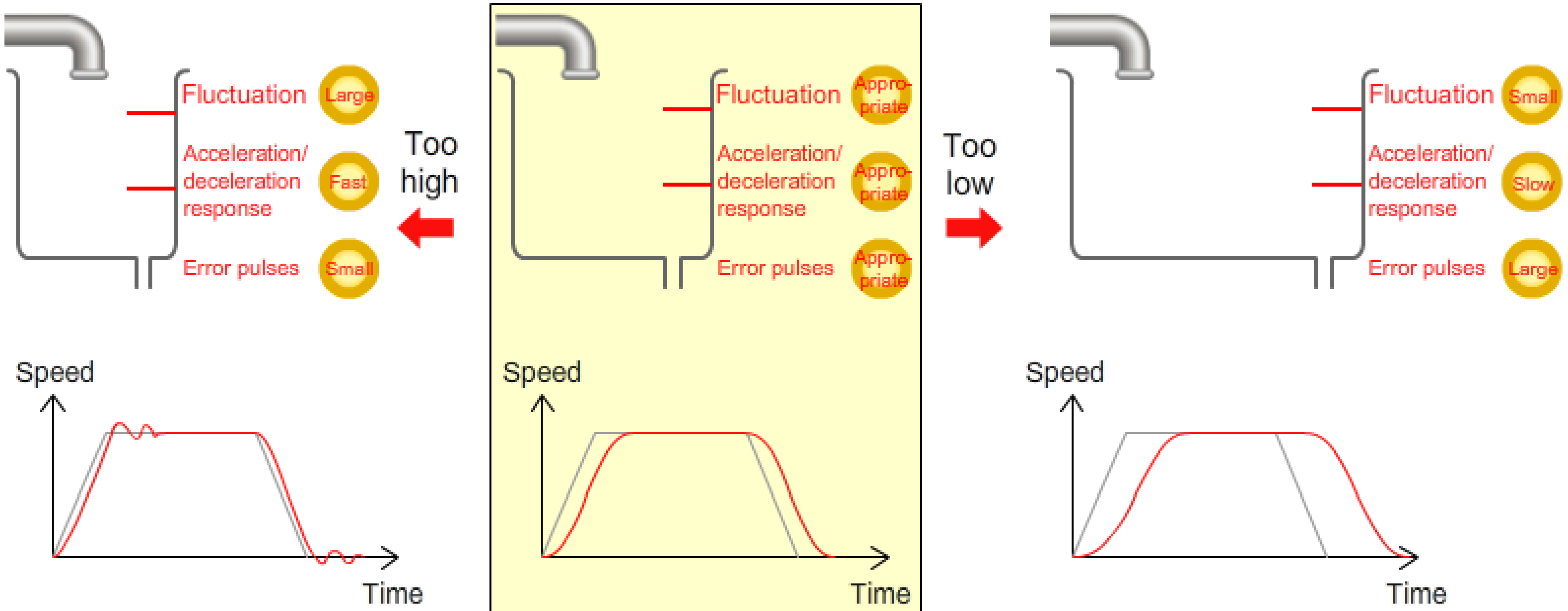
Error pulses act as a filter that removes the noise generated by command pulses and feedback pulses.
The value used to adjust the amount is called "position loop gain." When this value is optimal, feedback response improves in terms of speed profile and positioning accuracy.
Note that fluctuations in the position loop gain corresponds to fluctuations in the servo motor operation.

Image: Changing position loop gain = Changing the size of the error pulse container

Noise = Fluctuations of water surface → Fluctuations in speed command → Fluctuations in servo motor operation

Position loop gain

Too high > **Optimal state** > **Too low**



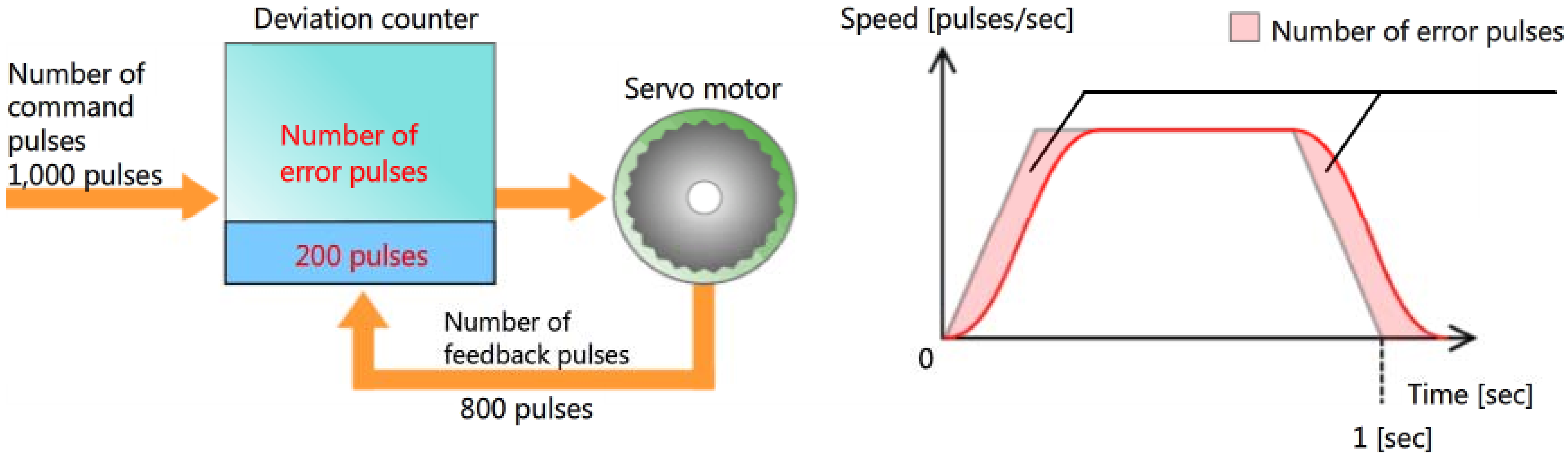
Over response resulted in stop position overshoot, noise generation, and unstable operation.

Optimal response. Ideal positioning speed and accuracy.

Stopping is smooth but takes too long.

2.4.3 Feedback Mechanism

Calculating the Position Loop Gain



The position loop gain can be calculated as shown below.

* Assumption: 1,000 command pulses, 800 feedback pulses, 1,000 [pulses/sec] of command pulse frequency

Number of error pulses = [Command pulses] - [Feedback pulses]

200 pulses = 1,000 pulses - 800 pulses

$$\text{Position loop gain} = \frac{\text{Command pulse frequency}}{\text{Number of error pulses}}$$

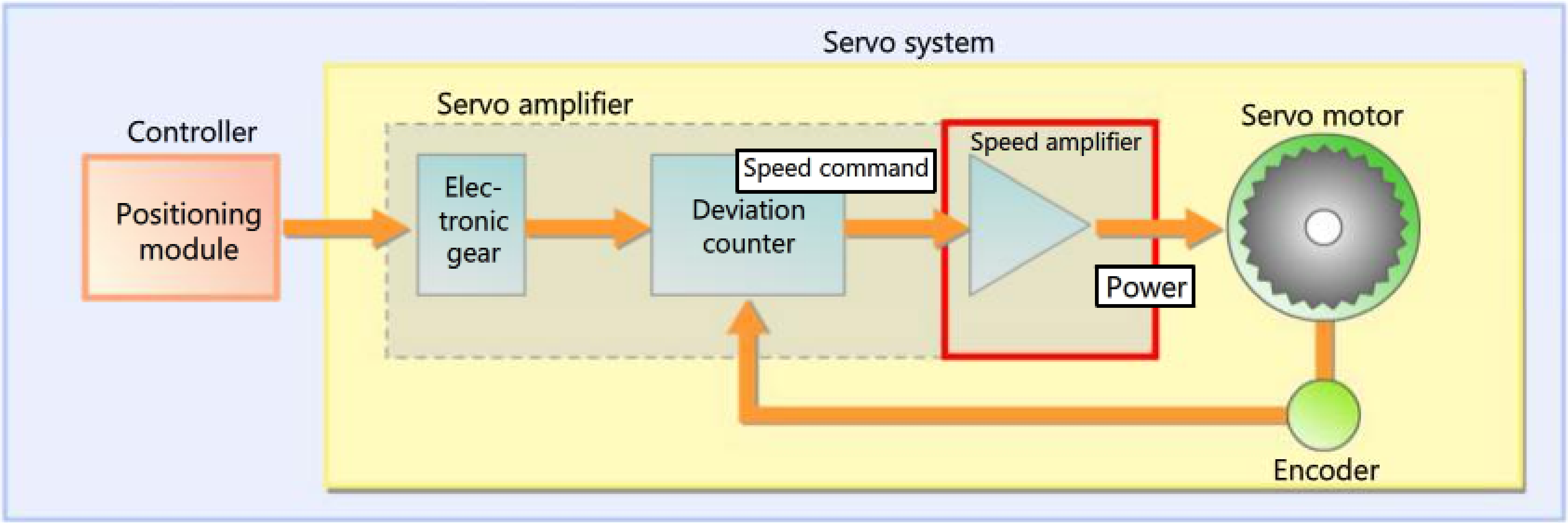
$$5\ [\text{rad/sec}] = \frac{1{,}000\ [\text{pulses/sec}]}{200\ \text{pulses}}$$

Position loop gain: 5 [rad/sec]

2.4.4 Role of the Speed Amplifier

The speed amplifier supplies power to the servo motor based on the speed command from the deviation counter.
The speed command is proportional to the number of error pulses in the deviation counter.

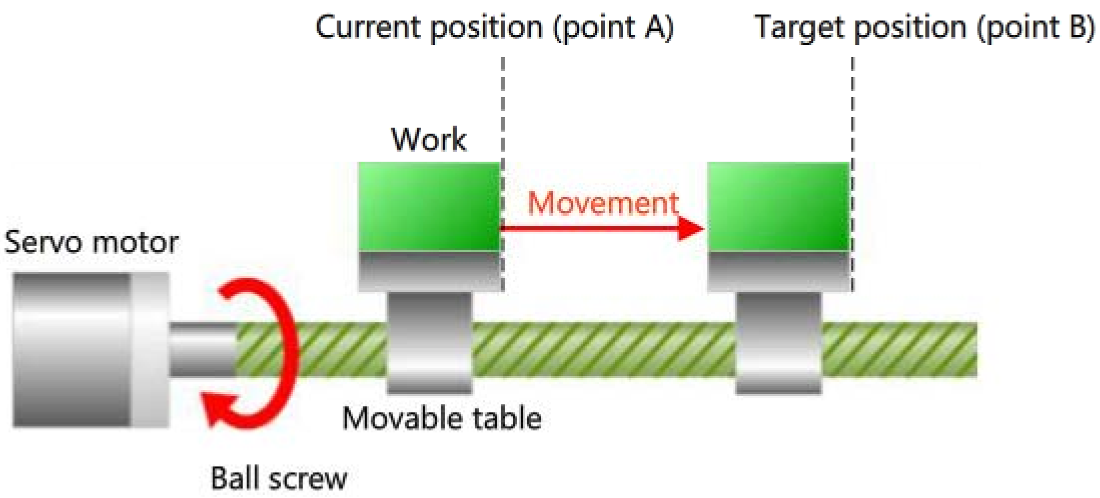
Number of error pulses	Speed command	Rotation speed of serve motor
Large	High	High
Small	Low	Low
Zero	None	Stopped



Chapter 3 How to Carry Out Positioning Control

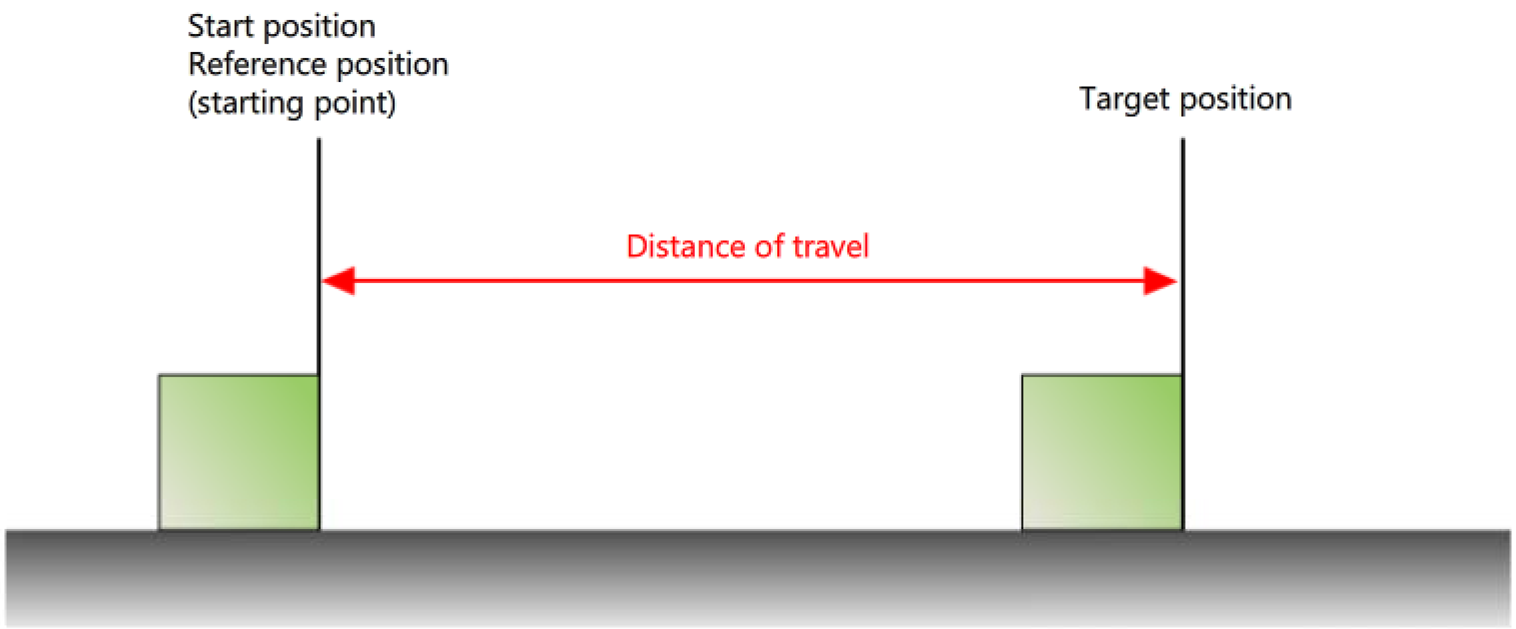
In this chapter, you will learn how to actually perform positioning.

In Section 3.3, you will study the positioning control system shown below.



3.1 Starting Point as Reference Position

In position control, the starting point is often used as the reference position.
The target position can be specified by determining the starting point.
Position control matches the target position with the reference position of the work.

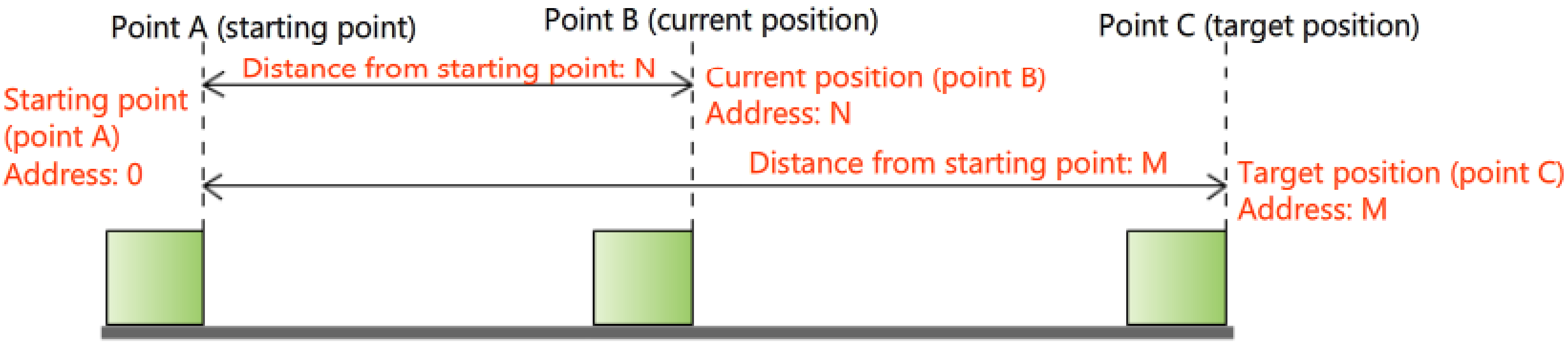


3.2 Address Designation Methods

There are two types of address designation methods: absolute address designation method (ABS) and incremental address designation method (INC). The target position specification differs depending on the address designation method used.

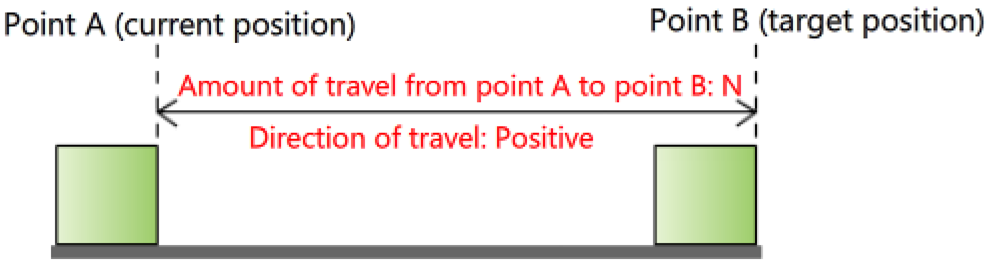
Absolute address designation method

In positioning control, the distance from the starting point is called "address." (The address of the starting point is "0".)
In the absolute address designation method, an "address" is specified at the positioning target position.
This method makes it easy to set the target position and is used for general machine control.



Incremental address designation method

The distance and travel direction from the current position to the target position is specified.
This address designation method is suitable for "constant-rate feeding" for repeatedly moving a given amount, such as feeding the paper of an ink jet printer.

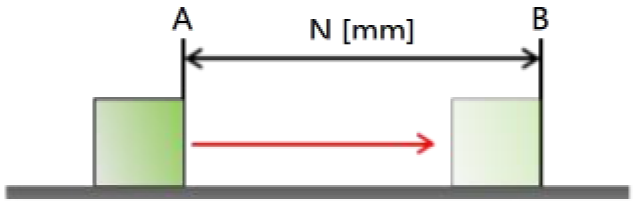


In the absolute address designation method, the distance travelled is the difference between the start position address and target position address.
In the incremental address designation method, the distance travelled is already specified.

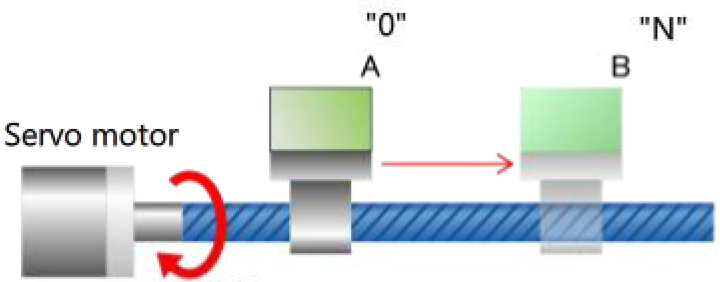
3.3 Positioning Control Design Procedure

Here, you will learn how to determine the number of command pulses and the command pulse frequency required to actually move the work from point A to point B.
The following figure shows the procedure to determine the number of command pulses and the command pulse frequency.

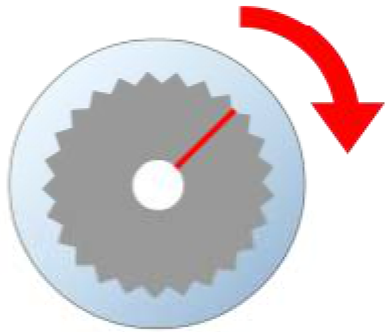
(1) Decide the travel distance (e.g. between points A and B) and time to reach the destination.



(2) Determine the rotational speed of the servo motor.



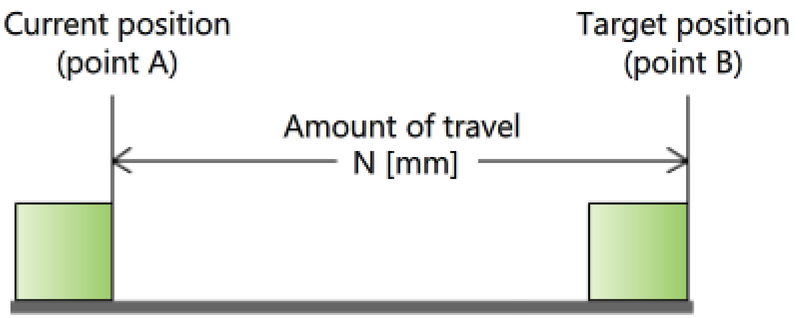
(3) Determine the number of command pulses and the command pulse frequency based on the resolution of the servo motor.

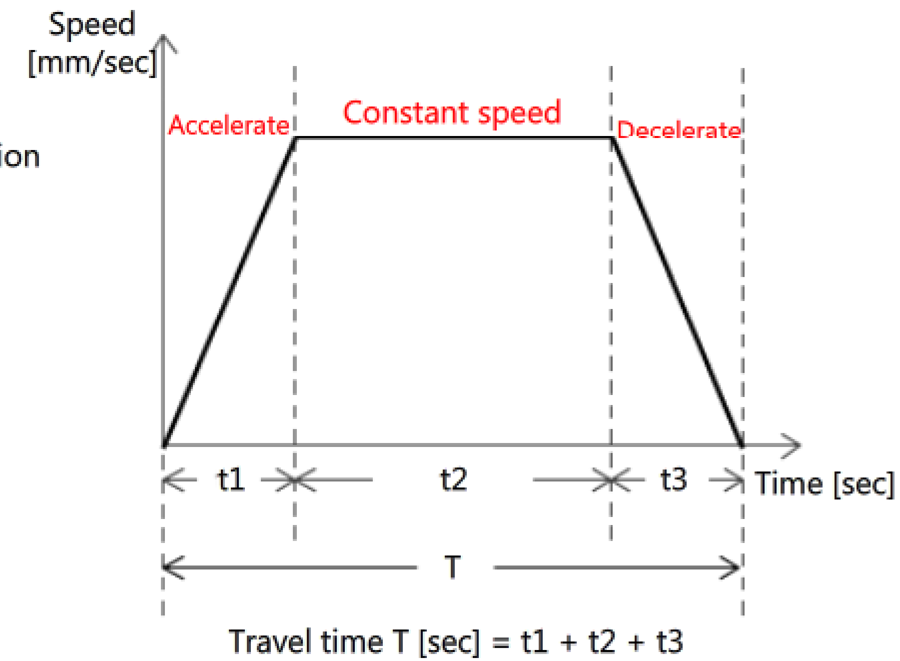


3.3.1 Deciding the Travel Distance and Speed of the Work

- Distance (N[mm]) is the difference between current position (point A) and target position (point B)
- Speed profile in T seconds. (T = t1 + t2 + t3)

The following figure shows the amount and speed of travel.



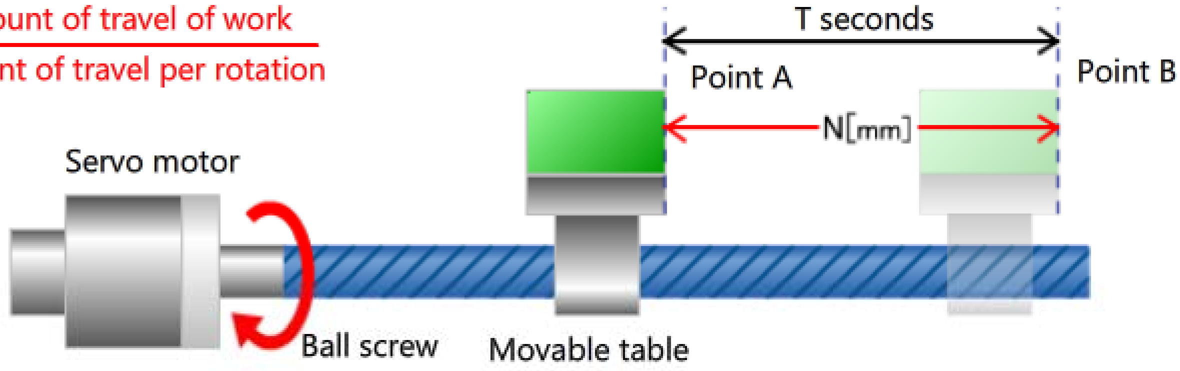


3.3.2 Angular Displacement and Speed of Servo Motor

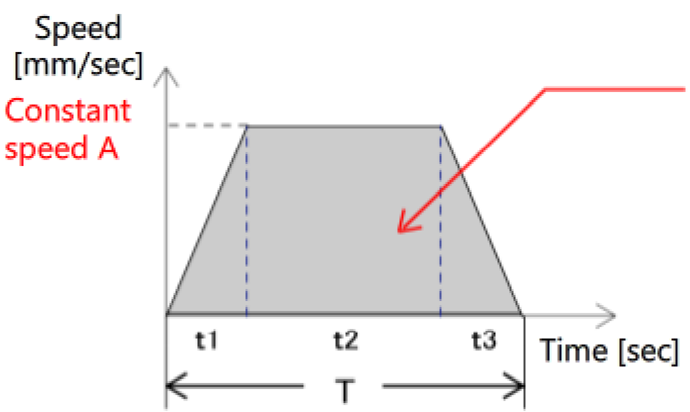
The positioning control system shown in the figure below is used to convert the rotational motion of the servo motor into linear motion.
The ball screw connected to the servo motor rotates to move the movable table.

If the distance traveled by the movable table during one rotation of the ball screw (servo motor) is known, then the number of rotations of the servo motor necessary to move the table from point A to point B can be calculated.

$$\text{Number of rotations} = \frac{\text{Amount of travel of work}}{\text{Amount of travel per rotation}}$$



Decide time T, and if t1, t2, and t3 are known, constant speed A can be calculated.



The area is the amount of travel N.

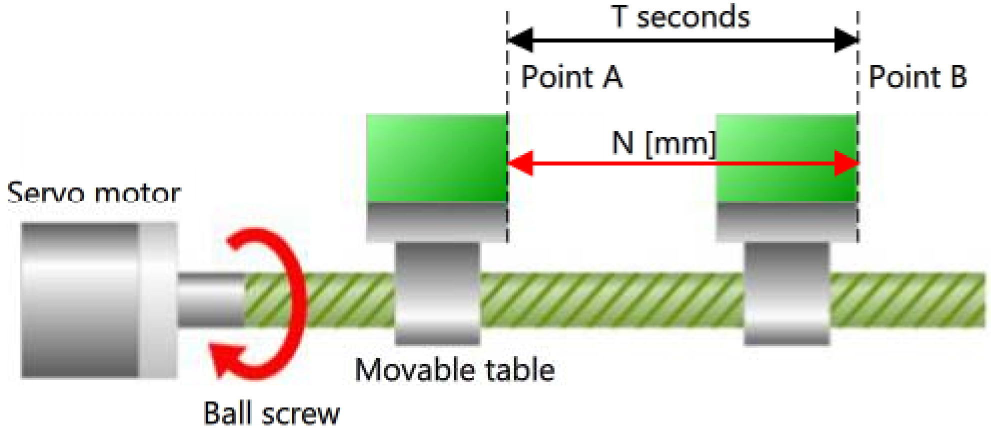
$$N = \frac{A \cdot t1}{2} + A \cdot t2 + \frac{A \cdot t3}{2}$$

$$\text{Constant speed A} = \frac{N}{\frac{t1}{2} + t2 + \frac{t3}{2}}$$

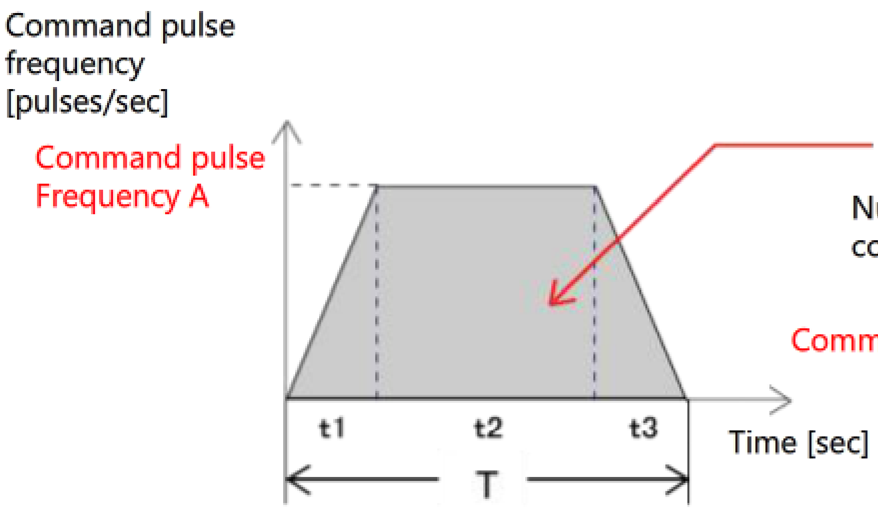
3.3.3 Determining the Number of Command Pulses and the Command Frequency

If the number of rotations and the resolution of the servo motor are known, the number of command pulses can be calculated.

Number of command pulses = Number of rotations x resolution



The command pulse frequency can be calculated from the travel time and the number of command pulses.



The area is the number of command pulses.

$$\text{Number of command pulses} = \frac{A \cdot t1}{2} + A \cdot t2 + \frac{A \cdot t3}{2}$$

$$\text{Command pulse frequency A} = \frac{\text{Number of command pulses}}{\frac{t1}{2} + t2 + \frac{t3}{2}}$$

Chapter 4 What to Consider in Actual Positioning

In actual positioning control, problems caused by the characteristics or errors of a machine must be considered.

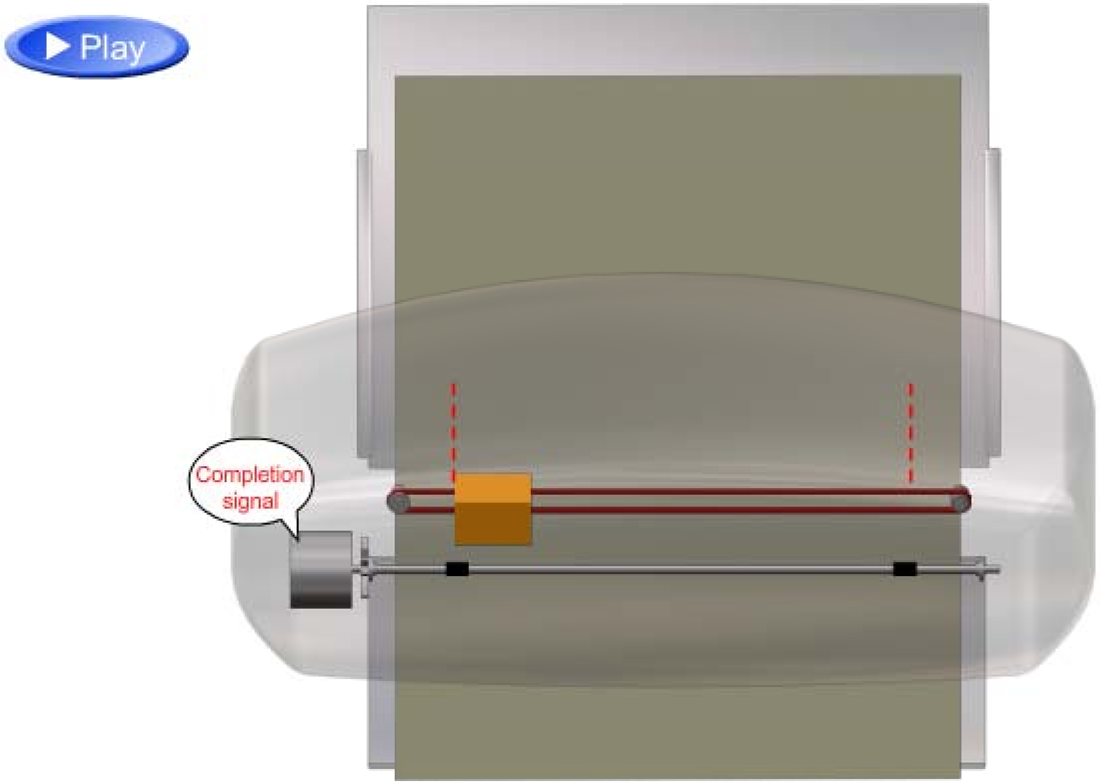
In this chapter, you will learn about how to implement the following types of positioning control in an actual situation.

- Smooth and continuous control
- Maintain position at the end of a transfer
- Prevent overshoot
- Align machine with starting point of positioning module
- Manually fine tune a position

4.1 Smooth and Continuous Control

To smoothly perform various types of continuous work, the servo amplifier outputs a "positioning completion signal" upon the completion of positioning.
The ink jet printer shown in the figure below can perform different types of positioning control, print head movement and paper feed, continuously and smoothly.

Press the "Play" button in the figure below to see the role of the positioning completion signal.

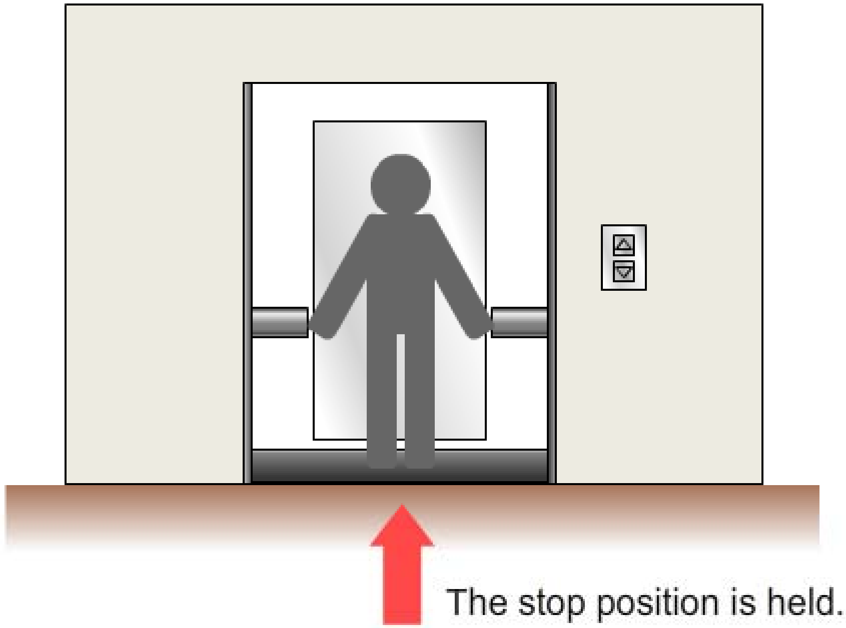


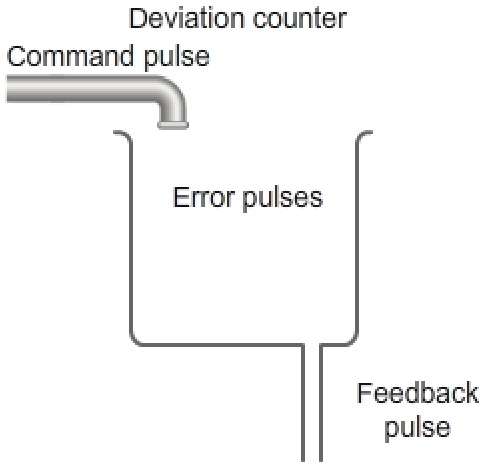
4.2 Maintain Position at the End of a Transfer

If the servo motor is rotated even by one pulse by an external force after completion of positioning control, feedback pulses are input to the deviation counter and error pulses are accumulated. The servo amplifier then supplies power to the servo motor, which generates a torque opposing the external force to keep the position fixed (stop position) by positioning control. This control is called "servo lock."

Play

Press the "Play" button to see the servo lock mechanism.

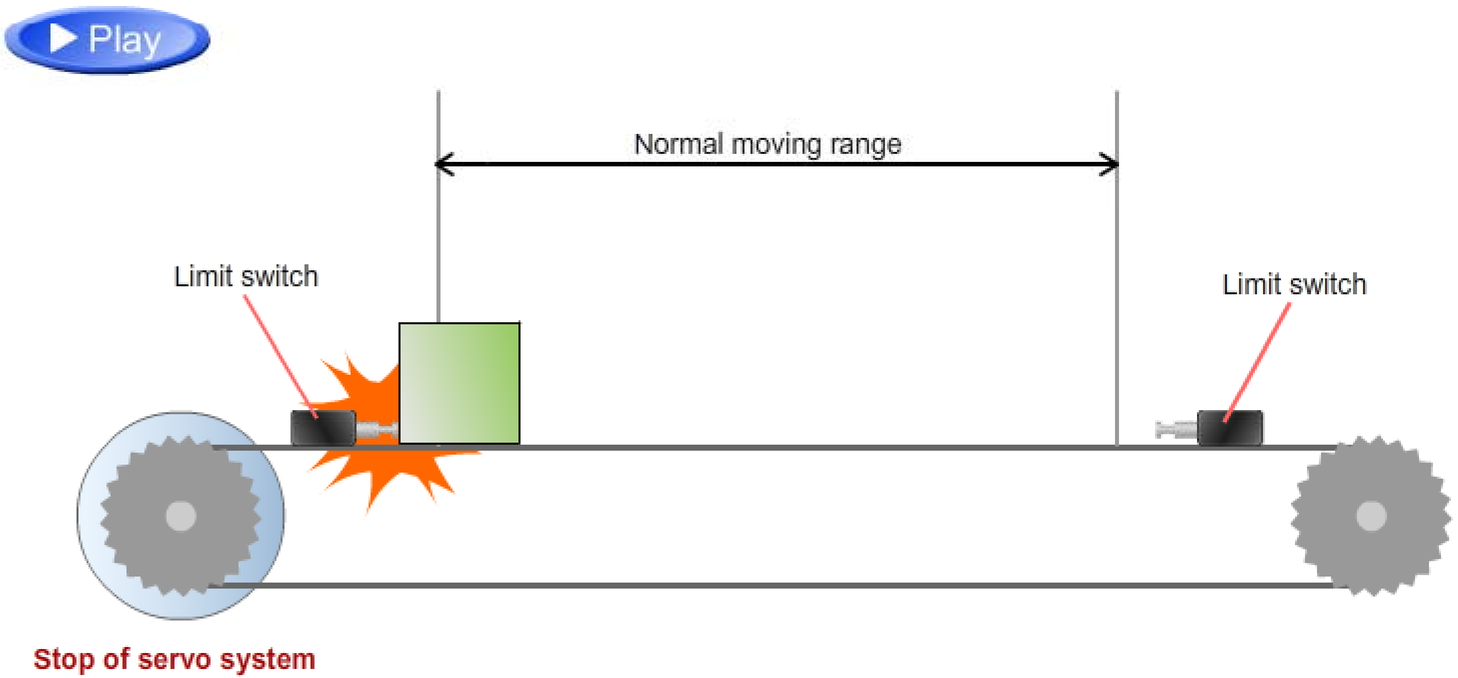




4.3 Prevent Overshoot

When positioning a work with the servo system, the servo system always positions the work at the position specified by the feedback mechanism.
However, in case of a program or command error, the servo motor may overrun, causing damage to the system and the work.
To avoid such damage, the servo system must be stopped urgently without relying on the program, and limit switches are provided at machine ends (normally, at two locations in the forward and reverse directions).

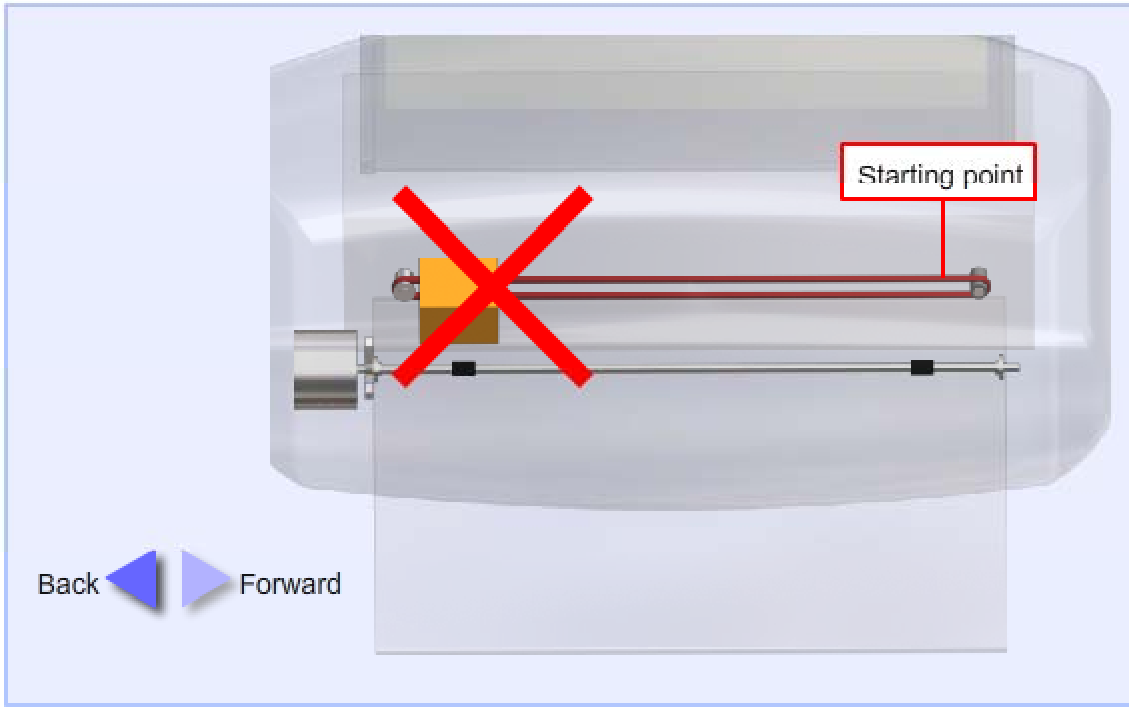
Press the "Play" button in the figure below to see the role of the limit switches.



4.4 Align Machine with Starting Point of Positioning Module

This is done by aligning the machine with the reference position (starting point) of the positioning module at power-on or assembly, which is also called "regaining machine datum".

Press the arrow button in the figure below to see the role of regaining machine datum.



- When the machine datum is not regained

The printer assumes that the stopped position is the starting point and starts printing from there.
Printing may be misaligned or the system may be damaged.

4.5 Manually Fine Tune a Position

Manual operation is mainly used to verify the operation of the positioning system, set the starting point and target position (address), or make fine adjustments during precise positioning.
There are three types of manual operations.

- JOG operation
- Inching operation
- Manual pulse generator operation

4.5.1 JOG Operation and Inching Operation

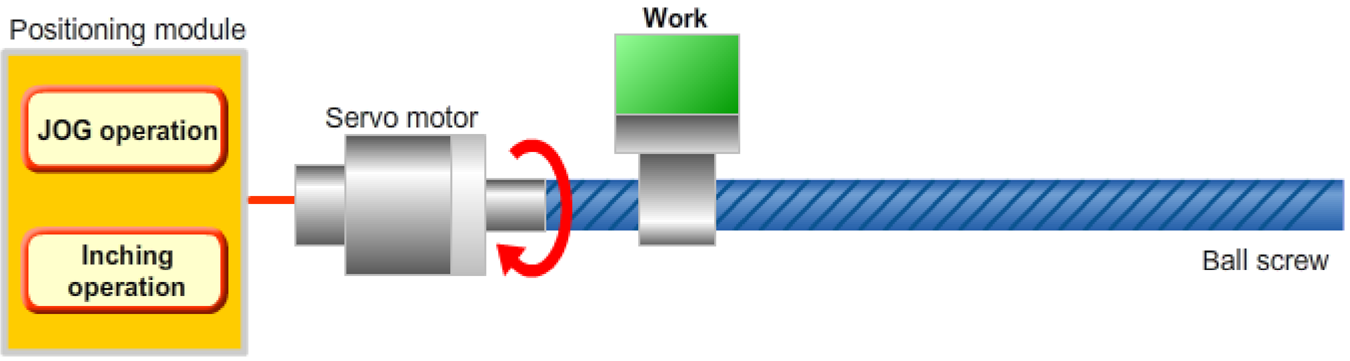
JOG operation and inching operation are modes in which a work is only moved by certain distance.
They are mainly used to:

- Verify the operation of the positioning system
- Setting the position address
- Fine tune the stop position

[Introduction of JOG operation and inching operation using a ball screw]

The following figure explains the JOG operation and inching operation.
The work keeps moving at a certain speed while the JOG Operation button on the positioning module is kept pressed.
The work moves a small distance in a constant cycle while the Inching Operation button on the positioning module is kept pressed.

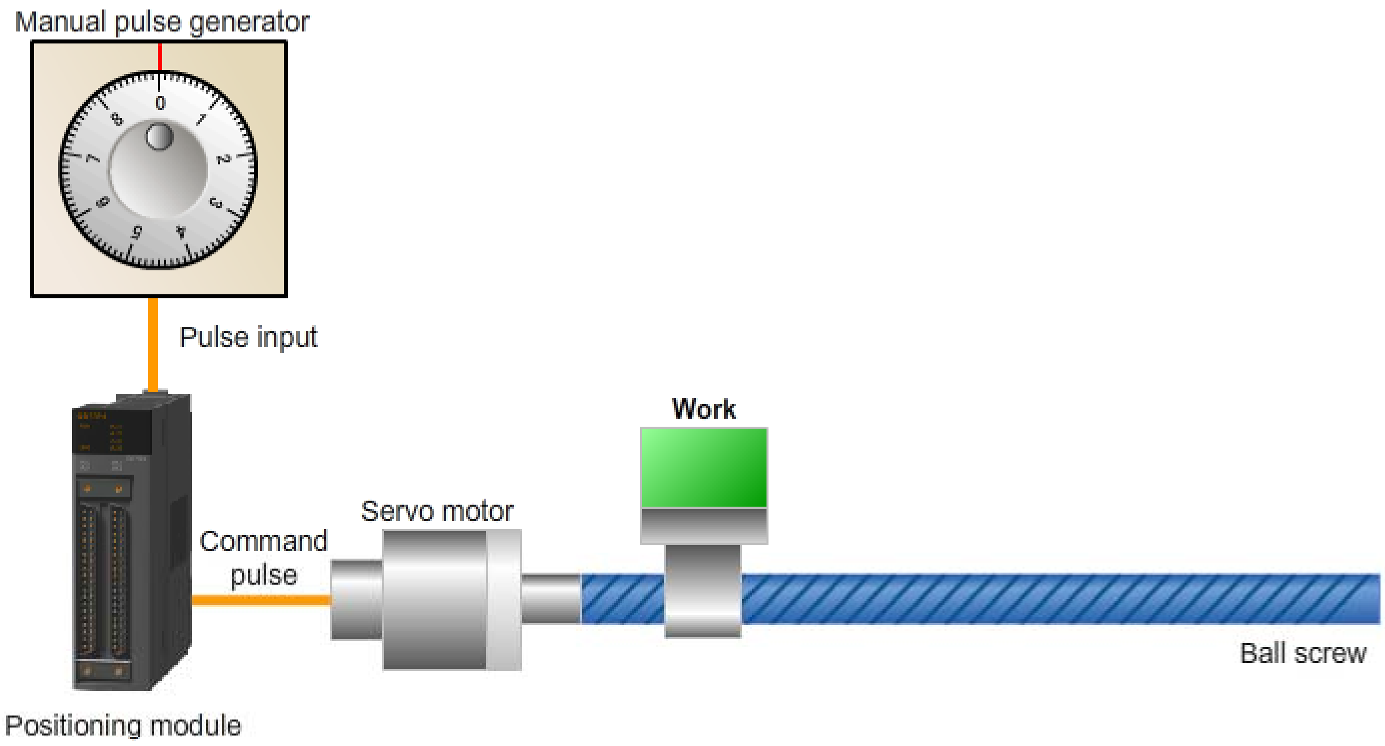
Press the JOG Operation and Inching Operation buttons on the positioning module in the following figure to check the respective operations.



4.5.2 Manual Pulse Generator Operation

In manual pulse generator operation mode, positioning is performed according to the number of pulses input from the manual pulse generator.
This operation mode is used when positioning needs to be finely adjusted manually to determine the positioning address (target position).

Using the mouse, turn the dial of the manual pulse generator in the figure below to check the manual pulse generator operation.
Turning the dial clockwise moves the work to the right and turning it counterclockwise moves the work to the left.



FA_Equipment_for_Beginners(Positioning)_ENG

Test | Final Test

Now that you have completed all of the lessons of the FA Equipment for Beginners (Positioning) Course, you are ready to take the final test. If you are unclear on any of the topics covered, please take this opportunity to review those topics.
There are a total of 7 questions (23 items) in this Final Test.
You can take the final test as many times as you like.

How to score the test

After selecting the answer, make sure to click the **Answer** button. Your answer will be lost if you proceed without clicking the Answer button. (Regarded as unanswered question.)

Score results

The number of correct answers, the number of questions, the percentage of correct answers, and the pass/fail result will appear on the score page.

Correct answers : 3

Total questions : 10

Parcentage : 30%

To pass the test, you have to answer **60%** of the questions correct.

Proceed | Review | Retry

- Click the **Proceed** button to exit the test.
- Click the **Review** button to review the test. (Correct answer check)
- Click the **Retry** button to retake the test again.

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Test | Final Test 1

Determine the number of command pulses.

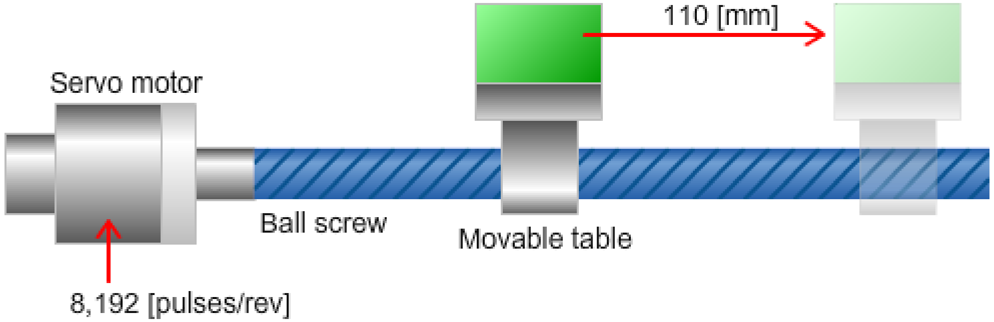
Select the appropriate option in each box.

The movable table travels 20 mm during one revolution of the ball screw. The encoder resolution is 8,192 pulses/rev. Under these conditions, determine the number of command pulses required to move the table 110 mm.

(1) Minimum amount of travel, travel per pulse : [▼] [mm]

(2) Number of revolutions of servo motor : [▼] revolutions

(3) Number of command pulses : [--Select-- ▼] pulses



Answer | Back

Test Final Test 2

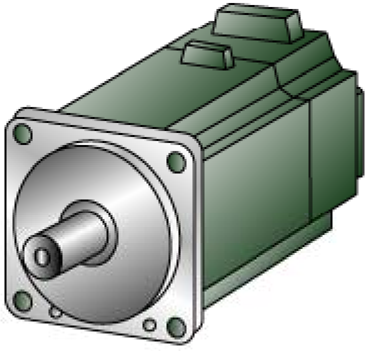
Determine the command pulse frequency.

Select the appropriate option in each box.

Determine the command pulse frequency required to revolve the servo motor at the rated revolving speed.

Encoder resolution : 8,192 pulses/rev

Rated revolving speed : 3,000 rpm



Command pulse frequency = [▼] x 3000 / [▼]

= [--Select-- ▼] [pulse/sec]

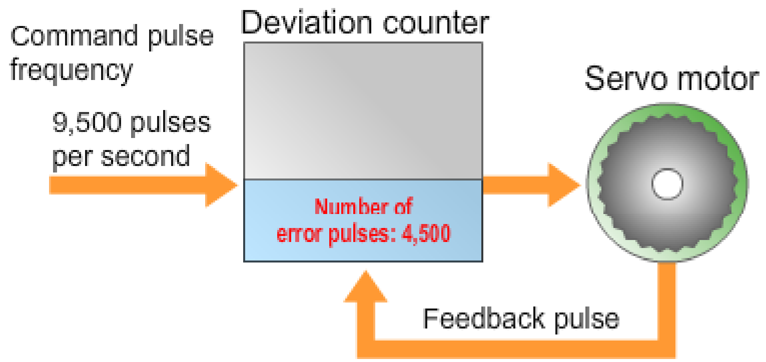
Encoder resolution of 16,384 pulses/rev is [--Select-- ▼] rpm.

Answer Back

Test Final Test 3

Determine the position loop gain and the method of adjusting the position loop gain.

Select the appropriate option in each box.



[Determine the position loop gain]

As shown in the figure, the command pulse frequency is 9,500 pulses/sec and the number of error pulses is 4,500.

Under these conditions, the position loop gain is [▼] rad/sec.

[Method for adjusting position loop gain]

Over responses of the servo motor may cause overshoot and noise. In this case, [--Select-- ▼] he position loop gain to [--Select-- ▼] the number of error pulses. This lowers the responsiveness of the servo motor and can adjust it to the optimum state.

Answer Back

Test Final Test 4

Set the electronic gear ratio.

Select the appropriate option in each box.

Determine the electronic gear ratio that enables the servo motor to operate at the rated revolving speed using the effective command pulse frequency. To enable the servo motor to operate efficiently, the following relation is establish between the maximum command pulse frequency, electronic gear ratio, resolution, and rated revolving speed.

[Relation]
Maximum command pulse frequency x electronic gear ratio >= resolution x rated revolving speed
(electronic gear ratio >= 1)

Select the optimum electronic gear ratio from the list under the following conditions.

[Conditions]
Maximum command pulse frequency of positioning module: 200k pulses/sec
Encoder resolution: 16,384 pulses/rev
Rated revolutions of servo motor: 2,000 rpm

[Optimal electronic gear ratio]

Command pulse frequency = --Select--

Answer Back

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Test Final Test 5

Questions about what matters should be taken into account for actual control

Select the appropriate option in each box.

Request/specification	Function
Wish to prevent overrun	--Select--
Wish to align the machine with the starting point of the positioning module.	--Select--
Wish to finely adjust the position manually.	--Select--
Wish to keep the position after completion of positioning.	--Select--
Wish to implement continuous control smoothly	--Select--

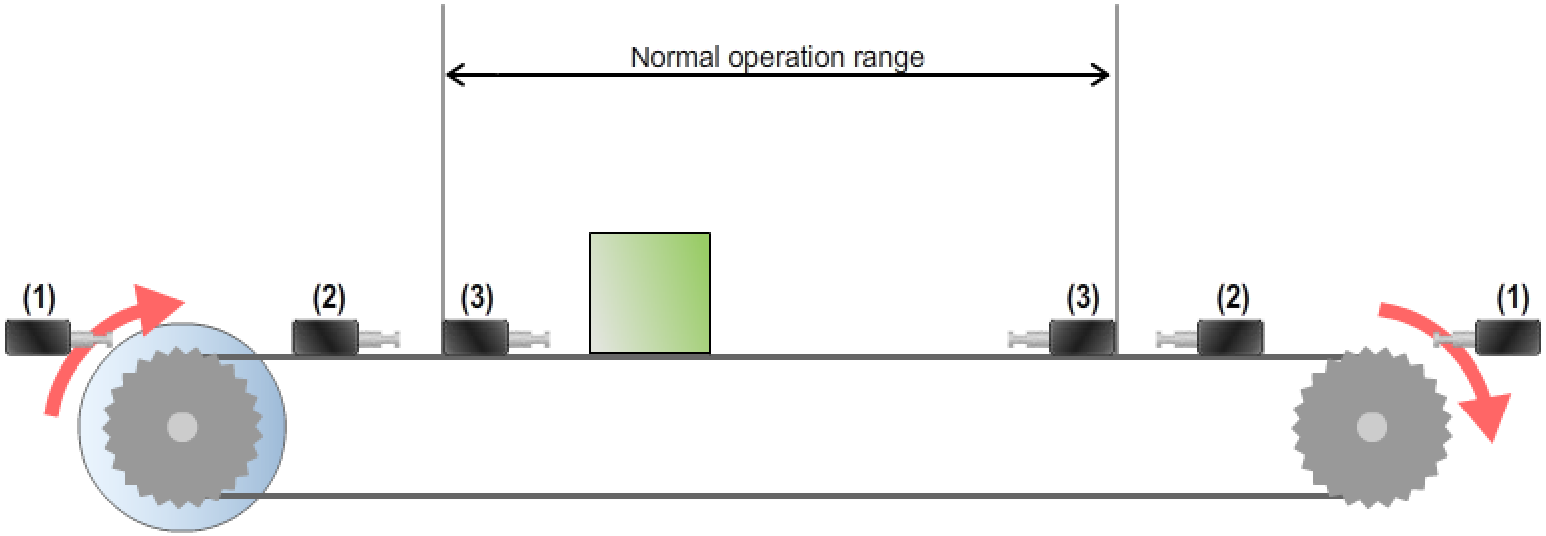
Answer Back

Test Final Test 6

Setting a limit switch

When constructing the positioning control system shown in the figure below, you wish to install a limit switch to prevent the system from overrunning the normal operation range.
Select the number indicating the optimal position where you should install the switch.

- (1)
- (2)
- (3)



Answer | Back

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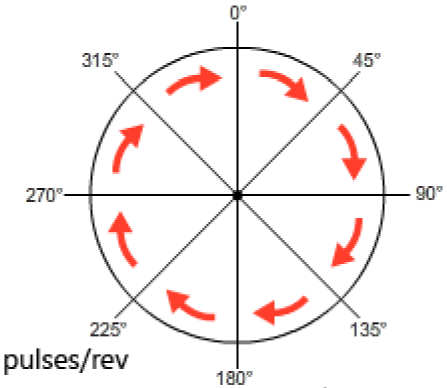
Test | Final Test 7

Absolute address designation method and incremental address designation method

The following tables explain the absolute address designation method and incremental address designation method.
Enter the appropriate numeric value in each box to complete the tables.



(1) To designate positions (angles) in increments of +45 degrees in order

Resolution: 8,192 pulses/rev

Angle	0°	45°	90°	135°	180°	225°	270°	315°	360°
Absolute address designation method	0	1024	▼	3072	▼	5120	6144	▼	8192
Incremental address designation method	0	+1024	+1024	+1024	+1024	+1024	+1024	+1024	+1024

(2) To designate various positions (angles) in order

Angle	0°	45°	180°	135°	315°	90°	270°	360°	225°
Absolute address designation method	0	1024	4096	3072	7168	2048	6144	8192	5120
Incremental address designation method	0	+1024	▼	-1024	▼	-5120	+4096	▼	-3072

Answer Back

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Test | Test Score

You have completed the Final Test. You results area as follows.
To end the Final Test, proceed to the next page.

Correct answers : 0

Total questions : 7

Pacentage : 0%

Proceed Review Retry

You failed the test.

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You have completed the FA Equipment for Beginners (Positioning) Course.

Thank you for taking this course.

We hope you enjoyed the lessons and the information you acquired in this course will be useful in the future.

You can review the course as many times as you want.

Review

Close