Sensors and Actuators: Servomotors and Servo Drives

Notes: From Omron Technical Guide

http://www.ia.omron.com/support/guide/14/introduction.html

ME 423: Machine Design
Instructor: Ramesh Singh

Outline

- Servomotors and Servo Drive
- Definition of key terms
- Selection of Servomotors

Servomotors & Servo Drive

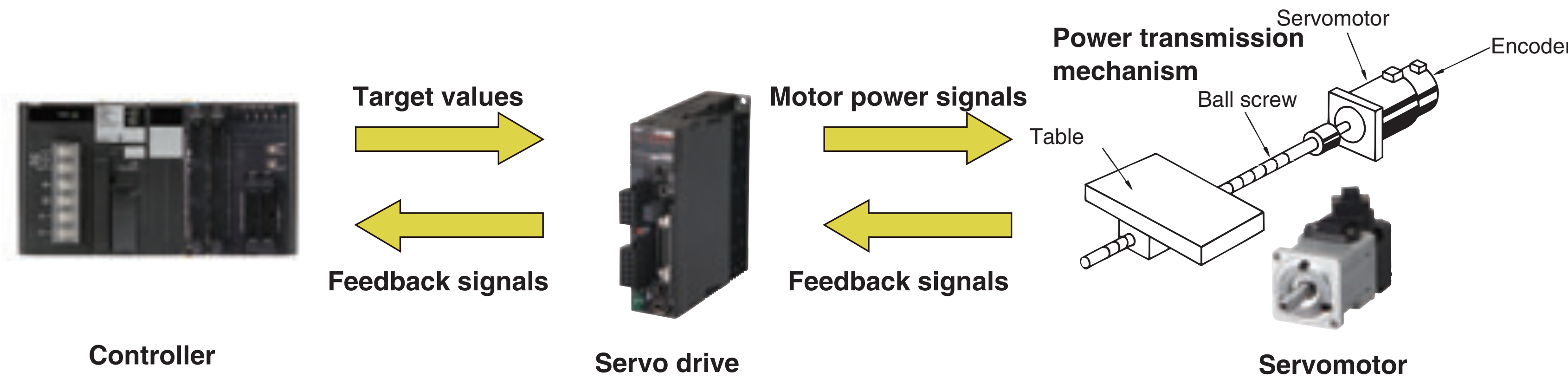
- A servomotor is a structural unit of a servo system and is used with a servo drive
- The servomotor includes :
  - Motor that drives the load
  - Position detection component, such as an encoder.
- The servo system varies the controlled quantity,
  - Position, speed, or torque, according to the set target value (command value) to precisely control the machine operation

Servo System Configuration

(1) Command section
Outputs command signals for operation.

(2) Control section
Controls the motor according to commands.

(3) Drive and detection section
Drives the controlled object and detects that object.



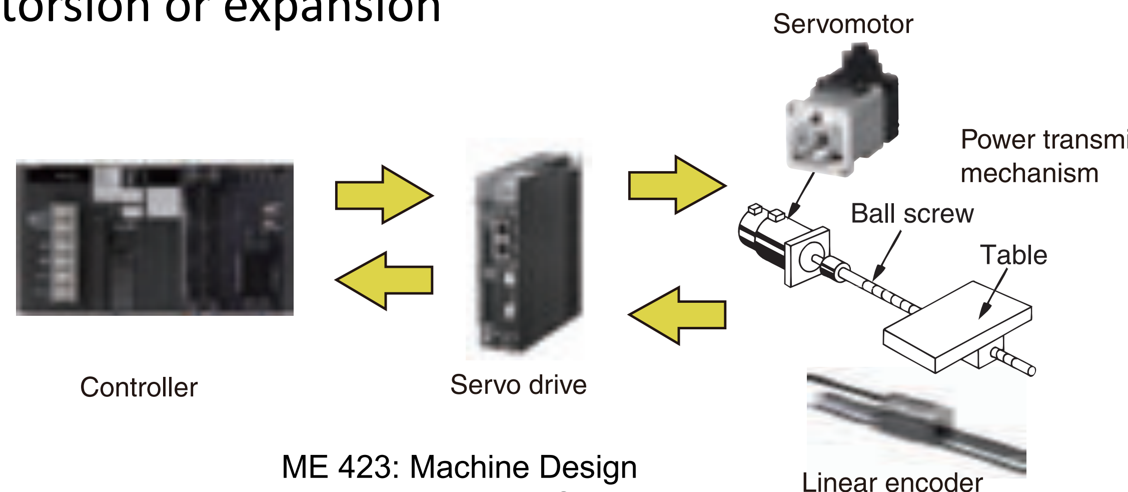
Courtesy: Omron

Features of Servomotors

- Precise, High-speed Control
  - Servomotors excel at position and speed control
  - Precise and flexible positioning is possible
  - Servomotors do not stall even at high speeds
  - Deviations due to large external forces are corrected because encoders are used to monitor movement.

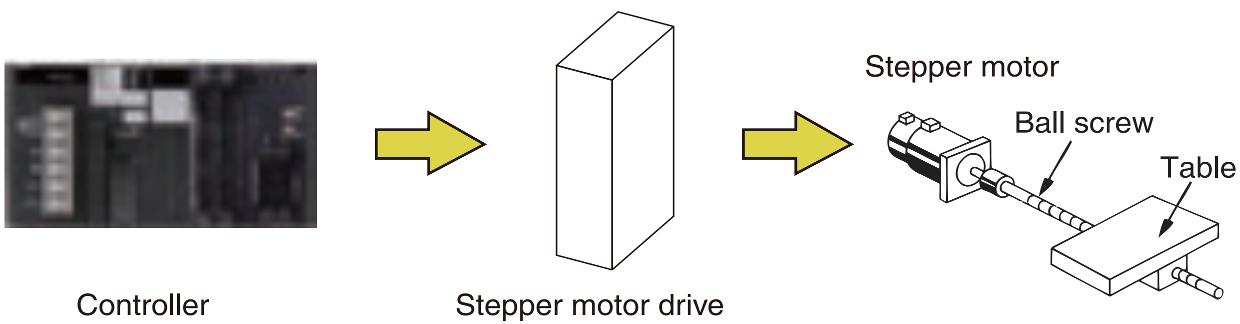
Fully-closed Loop

- The most reliable form of closed loop. A fully-closed loop is used when high precision is required.
- The motor is controlled while directly reading the position of the machine (workpiece or table)
  - Using a linear encoder and comparing the read position with the command value (target value)
  - Therefore, there is no need to compensate for gear backlash between the motor and mechanical system, feed screw pitch error, or error due to feed screw torsion or expansion



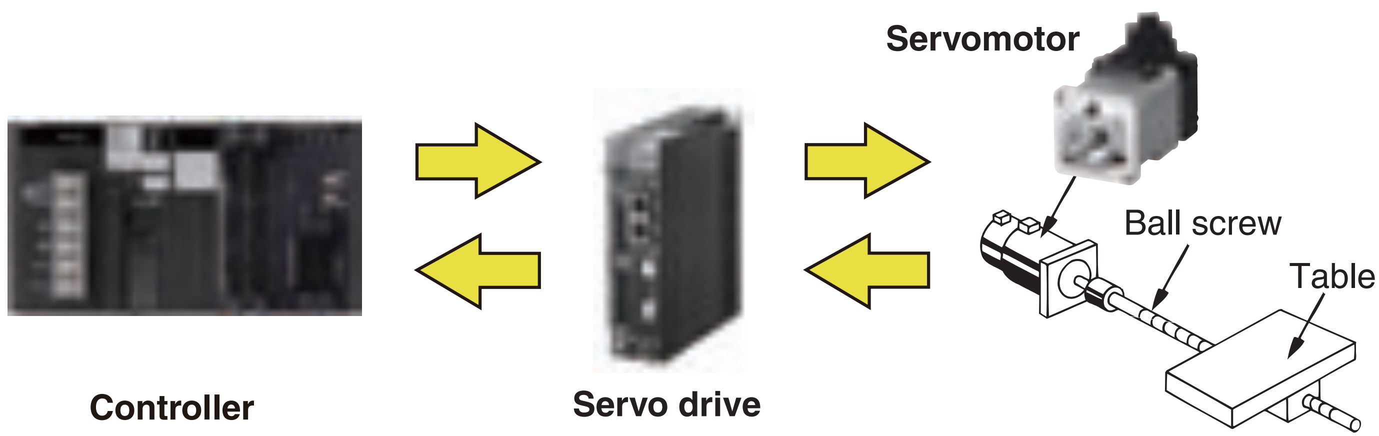
Open Loop

- A stepper motor is used instead of a servomotor. There is no feedback loop.
- The overall configuration is simple. Positioning can be performed at low cost, but gear and ball screw backlash and pitch errors cannot be compensated.
- When a stepper motor stalls, an error will occur between the command value and the actual movement. This error cannot be compensated.
- Open loop control is suitable for low-precision, low-cost, low- speed, and low-load-change applications.



Semi-closed Loop

- This method is commonly used in servo systems.
- It is faster and has better positioning precision than an open loop.
- Typically an encoder or other detector is attached behind the motor. The encoder detects the rotation angle of a feed screw (ball screw) and provides it as feedback of the machine (workpiece or table) travel position. This means that the position of the machine is not detected directly.
- The characteristics depend on where the detector is installed.



Location of Encoder

Installation location of detector	Behind motor	Motor side of feed screw	Opposite of motor side of feed screw
Gear backlash	Compensation required	Compensation not required	←
Ball screw or nut torsion	Affected	←	Hardly affected
Ball screw expansion or contraction	Affected	←	←
Ball screw pitch error	Compensation required	←	←

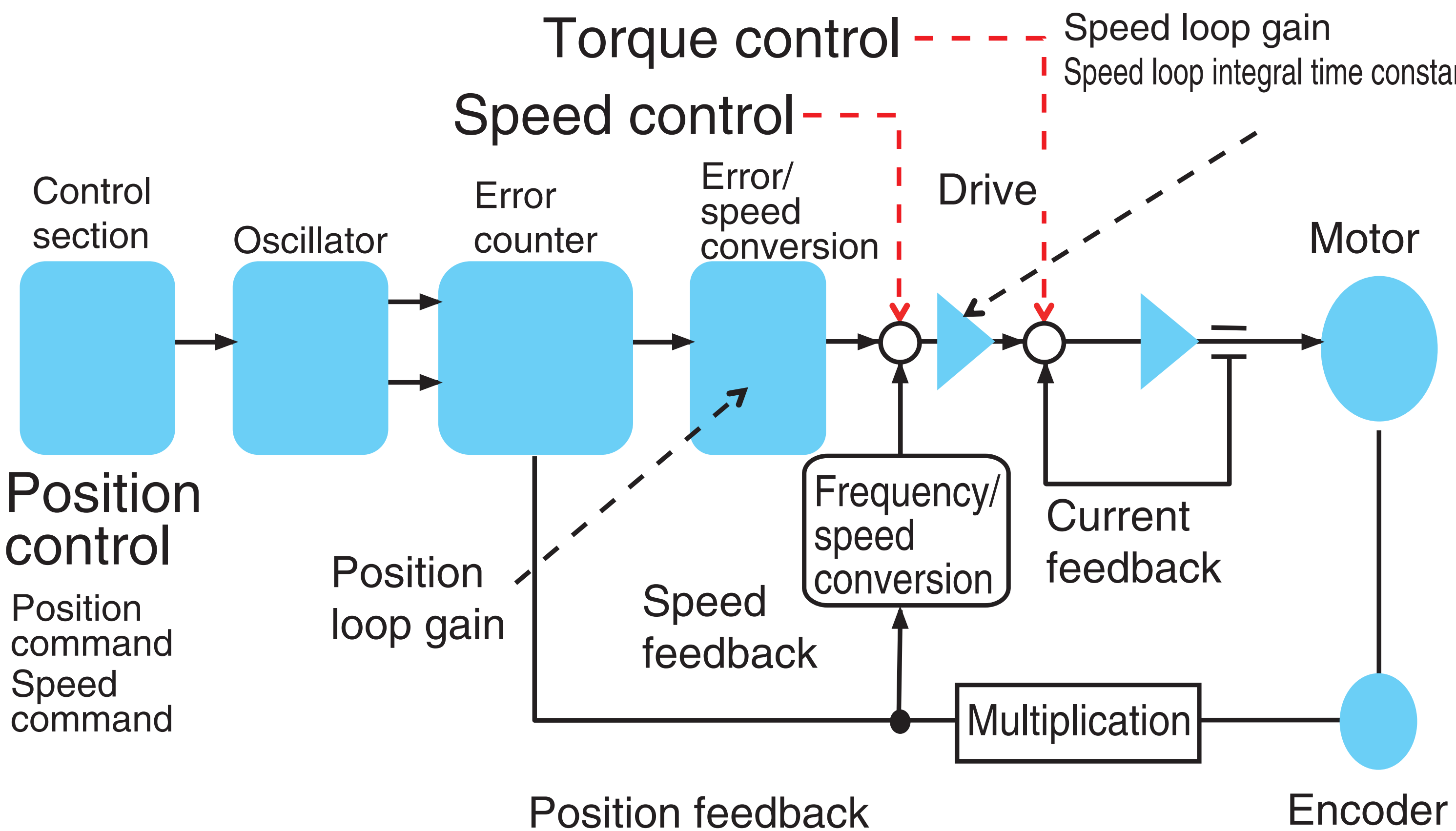
Servo Operation and Configuration

- Controls motor operation in closed loop
- The actual position, speed, or torque of the servomotor is fed back to compare to the command value and errors
- Then the servo drive corrects the operation of the servomotor in real time using this error
- This cycle of feedback, error detection, and correction is called closed-loop control.

Servo Operation

- The control loop is processed by either of servo drive or motion controller, or both
- The control loops for position, speed, and torque are independently used to achieve the required operation.
- Applications will not always require all three control loops
- In some applications, only the control loop for torque control will be required.
- In other applications, current and speed for speed control are required
- In some cases, three control loops for position control are required.

Principle

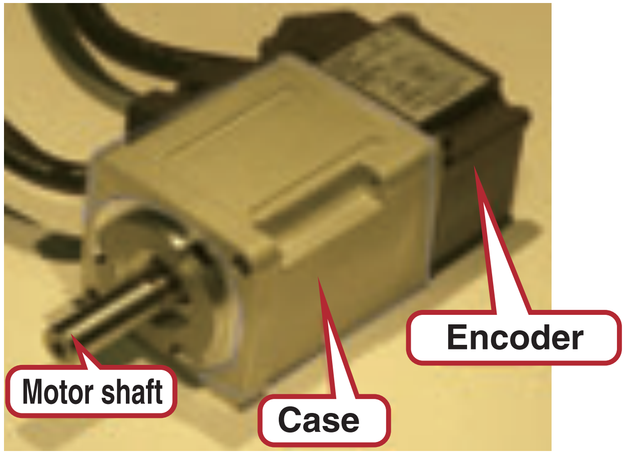


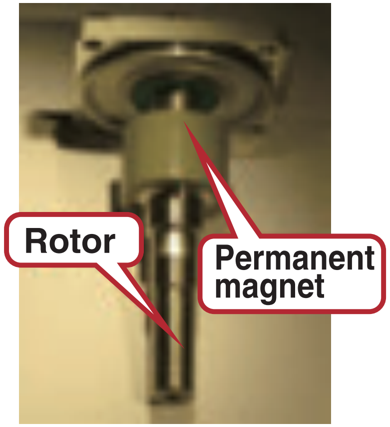
Torque control
Speed loop gain
Speed loop integral time constar
Speed control
Control section
Oscillator
Error counter
Error/ speed conversion
Drive
Motor
Position control
Position command
Speed command
Position loop gain
Speed feedback
Frequency/ speed conversion
Current feedback
Multiplication
Position feedback
Encoder

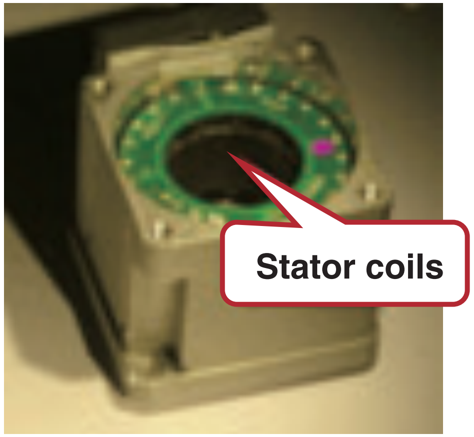
Servomotors

- Servomotors based on brushless motors are most common
- The rotor has a powerful permanent magnet
- The stator is composed of multiple conductor coils, and the rotor spins when the coils are powered in the specified order.
- The movement of the rotor is determined by the stator's frequency, phase, polarity, and current

Servomotors







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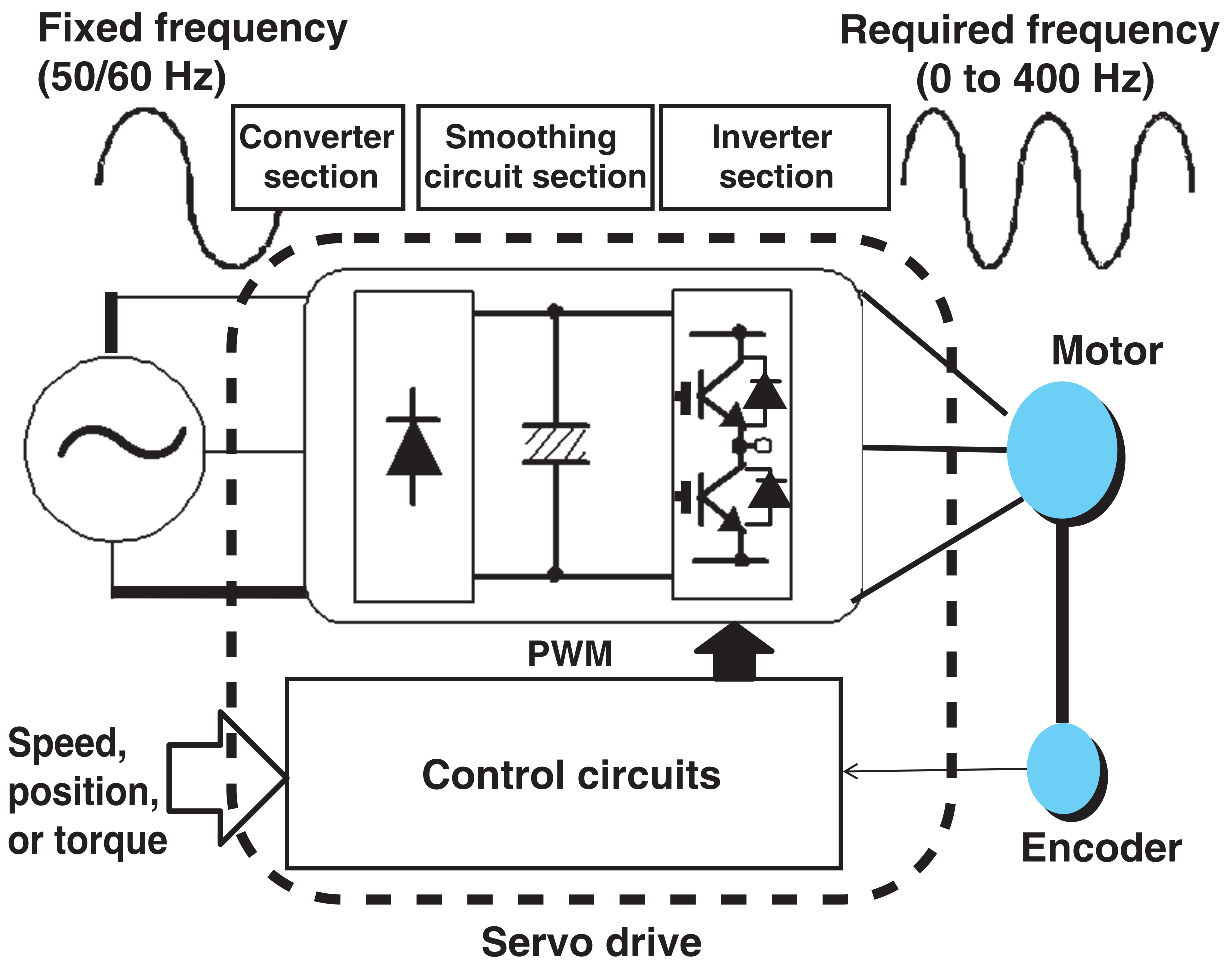
Encoders

- Servomotors are different from typical motors in that they have encoders. This allows high-speed and high-precision control according to the given position and speed commands
- Encoders are one of the hardware elements that form the core of a servo system, and they generate speed and position feedback.
- In many cases, the encoder is built into the servomotor or attached to the servomotor.
- In certain applications, the encoder is an independent unit that is installed away from the servomotor. When the encoder is installed in a remote location.
- Encoders are divided into two kinds:
  - Incremental encoders
  - Absolute encoders
- Multi-turn absolute encoders are typically used for servomotors

Servo Drive

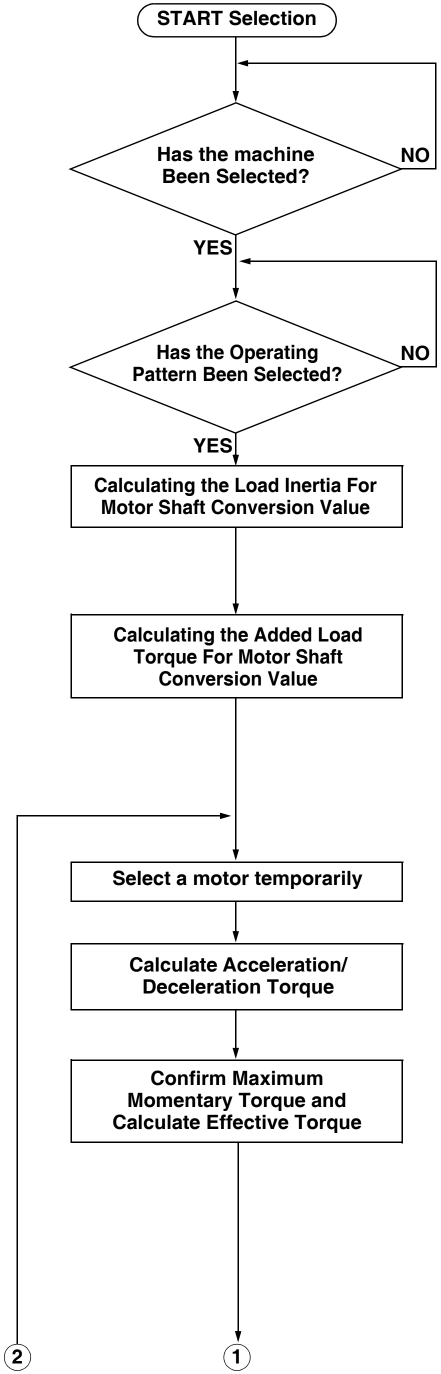
- Servo drives follow commands from the host controller and control the output torque, rotation speed, or position
- The position, speed, or torque are controlled according to inputs from a motion controller, feedback encoder, and the servomotor
- The servo drive supplies the appropriate amounts of power to the servomotor at the appropriate times.
- The basic operating principle is the same as for an inverter, in which the motor is operated by converting AC power to DC power to be a certain frequency

Servo Drive

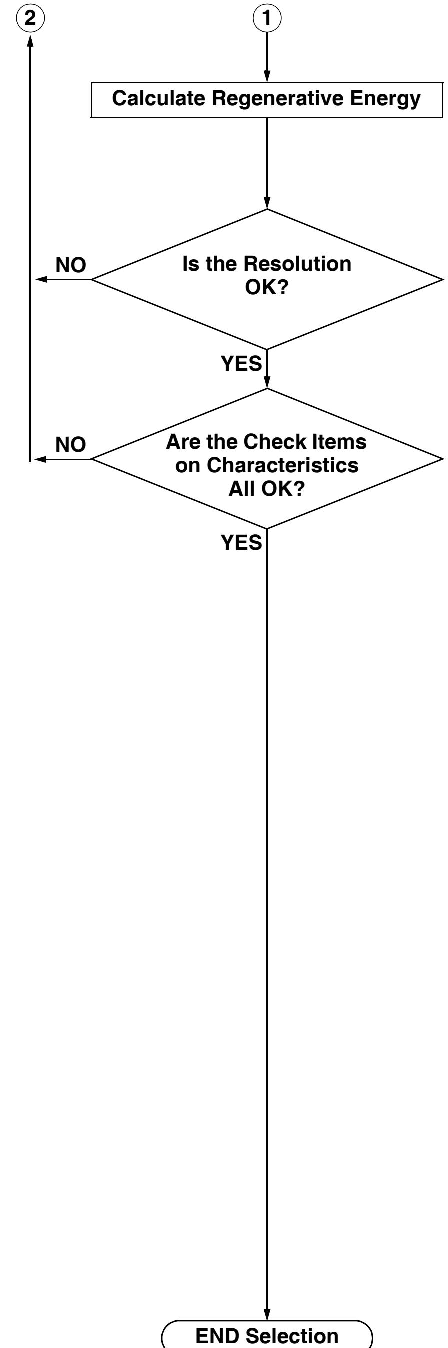

Fixed frequency
(50/60 Hz)
Required frequency
(0 to 400 Hz)
Converter section
Smoothing circuit section
Inverter section
Motor
PWM
Speed,
position,
or torque
Control circuits
Encoder
Servo drive

Functions of Servo Drive

- A servo drive also has the following functions.
  - Communications with the motion controller
  - Encoder feedback reading and realtime closed-loop control adjustment
  - I/O processing for safety components, mode inputs, and operating status output signals

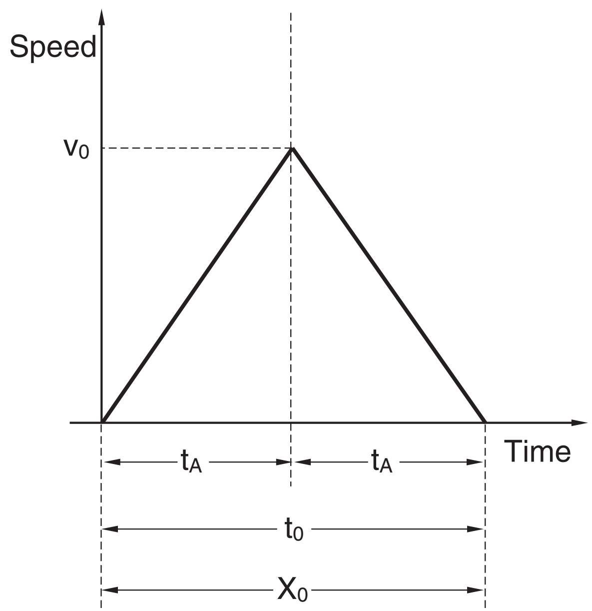


Explanation
• Determine the size, mass, coefficient of friction, and external forces of all the moving part of the servomotor the rotation of which affects.
• Determine the operating pattern (relationship between time and speed) of each part that must be controlled. • Convert the operating pattern of each controlled element into the motor shaft operating pattern.
• The elements of the machine can be separated so that inertia can be calculated for each part that moves as the servomotor rotates. • Calculate the inertia applied to each element to calculate the total load inertia of the motor shaft conversion value.
• Calculation of Friction Torque Calculates the frictional force for each element, where necessary, and converts it to friction torque for a motor shaft. • Calculation of External Torque Calculates the external force for each element, where necessary, and converts it to external torque of a motor shaft. • Calculates the total load torque for the motor shaft conversion value.
• Select a motor temporarily based upon the motor shaft converted load inertia, friction torque, external torque and r.p.m of a motor.
• Calculate the Acceleration/Deceleration Torque from the Load Inertia or Operating Pattern.
• Calculate the necessary torque for each part of the Operating Pattern from the Friction Torque, External Torque and Acceleration/Deceleration Torque. • Confirm that the maximum value for the Torque for each operating part (Maximum Momentary Torque) is less than the Maximum Momentary Torque of the motor. • Calculate the Effective Torque from the Torque for each Operating part, and confirm that it is less than the Rated Torque for the motor.



Operating Patterns: Triangular

Triangular



Maximum Speed $v_0 = \frac{X_0}{t_A}$

Acceleration/Deceleration Time $t_A = \frac{X_0}{v_0}$

Travel Distance $X_0 = v_0 \cdot t_A$

X_0: Distance Moved in t_0 Time [mm]

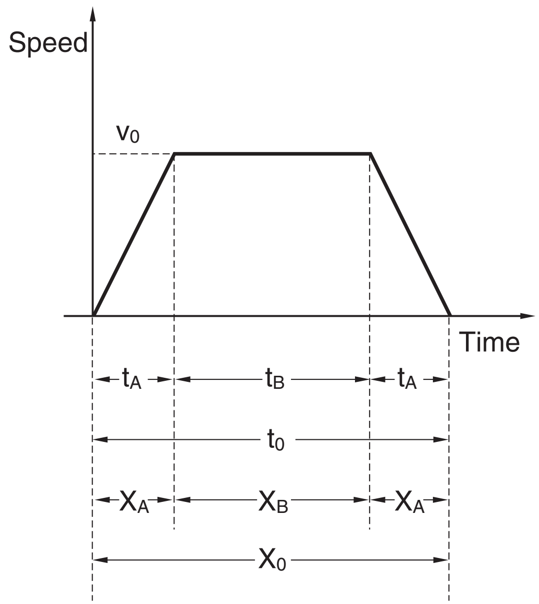
v_0: Maximum Speed [mm/s]

t_0: Positioning Time [s]

t_A: Acceleration/ Deceleration Time [s]

Operating Patterns: Trapezoidal

Trapezoid



Maximum Speed $v_0 = \frac{X_0}{t_0 - t_A}$

Acceleration/Deceleration Time $t_A = t_0 - \frac{X_0}{v_0}$

Total Travel Time $t_0 = t_A + \frac{X_0}{v_0}$

Constant-velocity travel time $t_B = t_0 - 2 \cdot t_A = \frac{2 \cdot X_0}{v_0} - t_0 = \frac{X_0}{v_0} - t_A$

Total Travel Distance $X_0 = v_0\ (t_0 - t_A)$

Acceleration/Deceleration Travel Distance $X_A = \frac{v_0 \cdot t_A}{2} = \frac{v_0 \cdot t_0 - X_0}{2}$

Constant-velocity travel distance $X_B = v_0 \cdot t_B = 2 \cdot X_0 - v_0 \cdot t_0$