CONTROL MODES OF OPERATION AND TUNING

CHAPTER 5

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Control Modes of Operation

*Sure*Servo drives can be programmed to provide six single and five dual modes of operation, as selected by parameter P1.01. The mode operations and descriptions are listed in the following table.

*Sure*Servo Control Modes of Operation				
Mode		**Symbol**	**P1.01**	**Description**
Single Mode	External Position Control (**P**osition - **t**erminals)	Pt	00	Position control for the servo motor is achieved via external pulse/count commands. Quadrature, pulse + direction, and CW/CCW are supported.
Single Mode	Internal Position Control (**P**osition - **r**egisters)	Pr	01	Position control for the servo motor is achieved via command positions stored within the servo drive. Selection of the 8 possible position preset setpoints occurs via Digital Input (DI) signals.
Single Mode	**V**elocity Control	V	02	Velocity control for the servo motor is achieved via an external analog ±10 Vdc command signal, or via velocity setpoints stored within the drive. Digital Inputs select either the analog signal or one of three internal setpoints.
Single Mode	Internal **V**elocity Control	Vz	04	Velocity control for the servo motor is achieved via velocity setpoints stored within the controller. Selection of the 3 velocity setpoints occurs via Digital Inputs (DI).
Single Mode	**T**orque Control	T	03	Torque control for the servo motor is achieved via an external analog ±10 Vdc command signal or torque setpoints stored within the drive. Digital Inputs select either the analog signal or one of three internal preset setpoints.
Single Mode	Internal **T**orque Control	Tz	05	Torque control for the servo motor is achieved via torque setpoints within the controller. Selection of the 3 torque parameters occurs via Digital Inputs (DI).
Dual Mode	Ext. Pos. - Velocity	Pt-V	06	Either Pt or V control modes can be selected via DI signals.
Dual Mode	Ext. Position - Torque	Pt-T	07	Either Pt or T control modes can be selected via DI signals.
Dual Mode	Int. Pos. - Velocity	Pr-V	08	Either Pr or V control modes can be selected via DI signals.
Dual Mode	Int. Position - Torque	Pr-T	09	Either Pr or T control modes can be selected via DI signals.
Dual Mode	Velocity - Torque	V-T	10	Either V or T control modes can be selected via DI signals.

How to Change Control Modes

1) Disable the servo drive by removing the Servo Enable signal.
2) Adjust parameter P1-01. (Refer to the Parameters chapter for more info.)
3) After changing the parameter value, power to the drive must be cycled for the change to take effect.

The following sections describe the operation of each control mode.

Position Control Modes

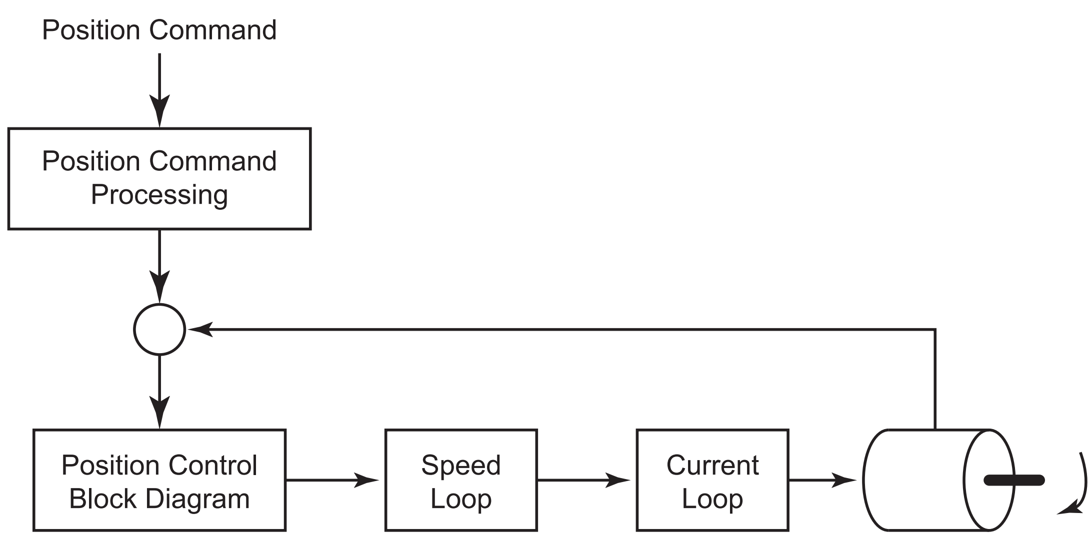
The position control modes (Pt or Pr mode) are used in applications requiring precision positioning, such as index tables, slides, etc. The *Sure*Servo drive supports two kinds of command sources in position control mode. One is an external pulse train (**Pt**: Position-Terminals), and the other is internal parameter settings (**Pr**: Position-Registers; the drive's **Internal Indexer** function).

In order to provide a convenient position control function, the *Sure*Servo drive's **Internal Indexer** function provides eight internal preset position parameters for position control. The selection of which position command to use comes from three digital inputs. While this allows the inputs to select eight possible command positions, the actual number of selectable positions is infinite since each parameter is addressable via the Modbus interface. The Pr mode also allows for **Index Mode** (to control rotary tables, tool changers, etc.) and **Auto Position Mode** (for sequencing multiple moves together).

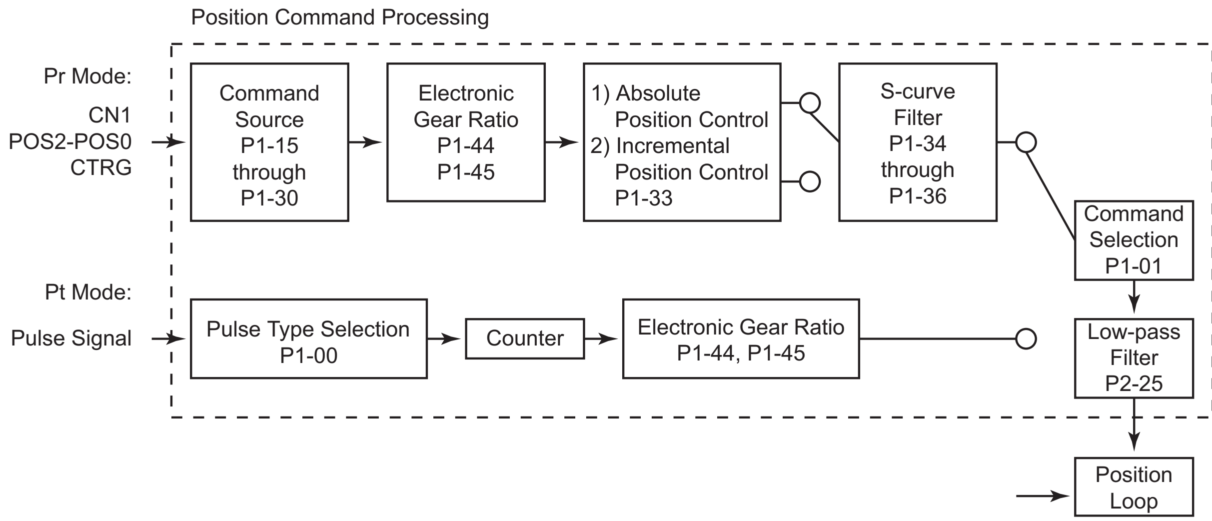
To allow the servo motor and load to operate more smoothly, the *Sure*Servo drive also provides complete Position Spine Line (S-curve) profile for position control mode. For closed-loop positioning, users may need to set not only the velocity control parameters, but also the position loop gain and feed forward compensation parameters. Three different tuning modes (Manual/Auto/Easy) allow the user to choose simple gain set-ups or to fine-tune the servo system with complete tuning flexibility. This chapter describes the applicability of loop gain adjustment, feed forward compensation, and tuning technology of *Sure*Servo systems.

Structure of Position Control Modes

Basic Block Diagram of Position Control (Pt and Pr)



Basic Block Diagram of Position Command Processing



The **Electronic Gear Ratio** (P1-44, P1-45) can be used in both Pt and Pr modes to configure the proper scaling of input pulse signals to output motor positioning. *Sure*Servo drives also provide a **Low-pass Filter** (P1-8) for Pt and Pr modes, and a **S-curve Filter** (P1-34, P1-35, P1-36) for Pr mode. Explanations of these settings follow later in this chapter.

Electronic Gear Ratio

Electronic gear ratio = (N_1/M) = (P1-44)/(P1-45).

The electronic gear setting range should be $(1/50) \leq (N_1/M) \leq 200$.

The Electronic Gear Ratio (EGR) is the number of output counts divided by the number of input pulses. It allows the user to scale the high-velocity positioning pulses coming into the drive, and is used to set some number of command counts to a unit of measure. For example: on a linear slide application, the input pulses can be scaled by electronic gearing so that 1 input pulse = 1 mm of travel. Electronic Gearing can also be used to increase the velocity at which the controller can command the motor to move. For example: Without electronic gearing (EGR = 1), a PLC that could only output a maximum pulse stream of 5kHz, would yield a 30 rpm maximum motor velocity:

(5,000 pulse/sec)(60 sec/min)(1 count/pulse) / (10,000 count/rev) = 30 rpm.

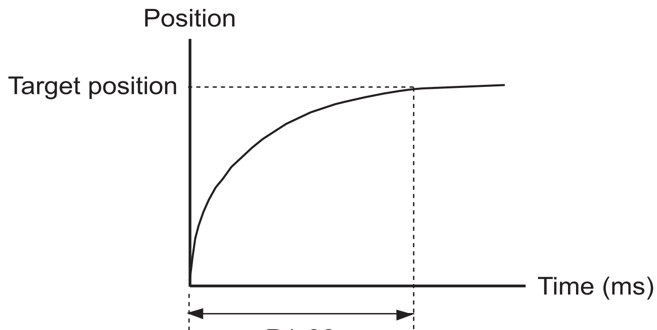
By inserting an Electronic Gear Ratio of 100:1, the 5kHz PLC could command the motor at a maximum of 3000 rpm. (EGR = output counts / input pulses)

(5,000 pulse/sec)(60 sec/min)(100 count/pulse) / (10,000 count/rev) = 3,000 rpm.

There are tradeoffs when using Electronic Gearing. While the above example will allow a 5kHz PLC output to move a *Sure*Servo motor at 3000 rpm, the downside is that the system loses resolution. While the motor still has a hardware resolution of 10,000 individual positions per resolution, every command pulse now coming into the *Sure*Servo drive causes the motor to increment its position by 100 motor counts.

Position Command Low-pass Filter

The low pass filter (LPF) smoothes the incoming command pulses (in Pt mode), and the command step changes (in Pr mode). This feature can be used to reduce vibration inherent in some very rigid systems. The LPF can also smooth the motor reaction to systems that have erratic pulse inputs (generated by encoders, sensors, etc.). P1-08 sets the LPF, and a value of 0 disables it.



Low-pass Filter

Position Loop Gain Adjustment

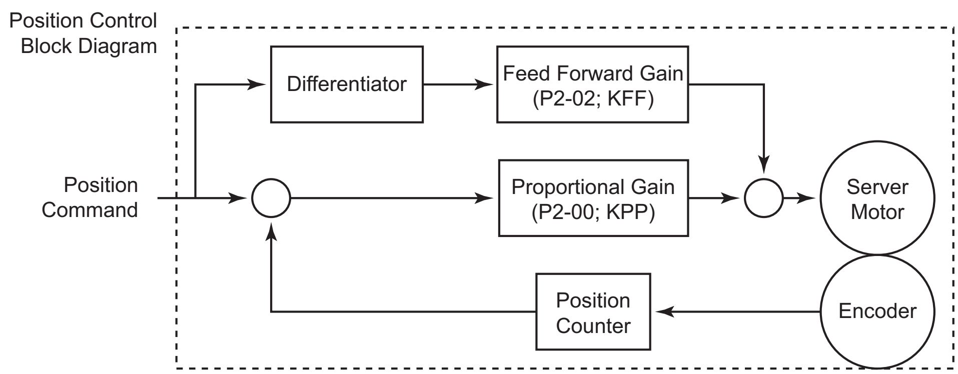
Before performing position control, the user should complete the velocity mode tuning, since position loop control depends on the velocity loop. (Refer to the "Tuning Modes" sections of this chapter for information on tuning methods.)

The position loop is adjusted by the Position Loop Proportional Gain, KPP (P2-00), and the Position Feed Forward Gain, KFF (P2-02). Increasing KPP will increase the response **bandwidth** of the position loop, and increasing KFF will reduce the phase delay time during operation. The phase delay will approach zero when the KFF setting is close to 100%.

(The response **bandwidth** is the frequency at which the system re-evaluates the position error. Higher bandwidths yield faster output responses, while lower bandwidths yield slower output responses.)

Since the Position Loop response is dependent upon the Velocity Loop, it is recommended that the Velocity Loop be at least four times faster than the Position Loop. This means that the Velocity Loop Proportional Gain, KVP (P2-04), should be at least four times larger than the Position Loop Proportional Gain, KPP (P2-00).

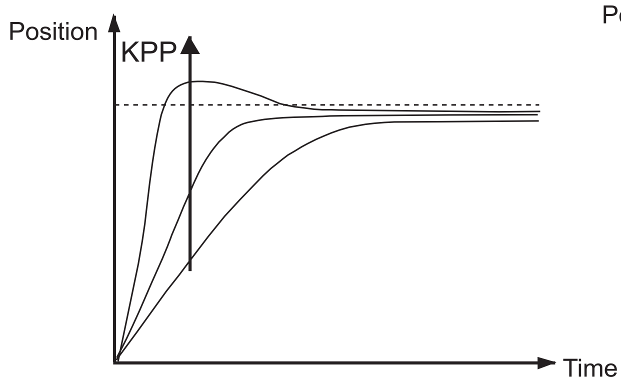
- The Position Loop Proportional Gain (KPP) is defined as:
  KPP = $(2)(\pi)(f_p)$ where f_p is the bandwidth of the position loop response.
- The Velocity Loop Proportional Gain (KVP) is similarly defined as:
  KVP = $(2)(\pi)(f_v)$ where f_v is the bandwidth of the velocity loop response.
- So, the bandwidths should have the following relation:
  $f_p \leq (f_v)/4$.

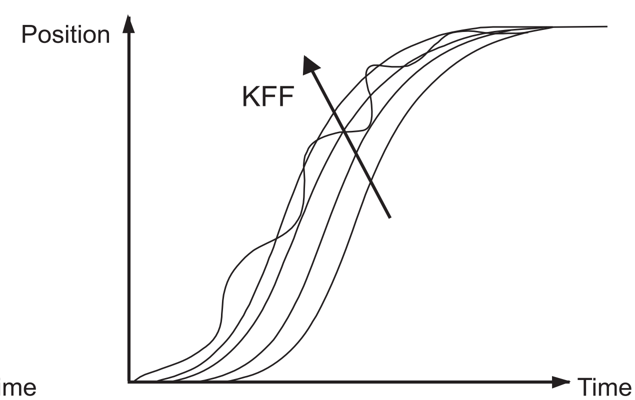


When the value entered into the Proportional Gain (KPP) is too great, the bandwidth of the position loop will be too high and there will be a small phase margin. When this happens, the motor's rotor will begin to oscillate. The motor will continually overshoot and undershoot its command position, and will eventually fault due to position error or overload. Decrease the value of KPP until the rotor does not violently vibrate. A low value of KPP will cause the motor to lose position when there is a disruption caused by the load. If there is not enough gain, then the motor will not overcome external forces to drive the motor into its commanded position.

Adjust the Feed Forward Gain (KFF) to reduce the dynamic position following error. The following graphs illustrate the effects of increasing KPP and KFF.

KPP = Position Loop Proportional Gain (P2-00)
KFF = Position Feed Forward Gain (P2-02)





Command Source of Pt Position Control Mode

The command source of the **Pt** (Position - terminals) mode comes from an external pulse train. Parameter P1-00 selects one of the three possible types of pulse inputs, and the polarity of the signals. The three possible position input types are Pulse/Direction, CW/CCW, and Quadrature. Refer to the Parameters chapter for details.

The position command pulse inputs (terminals 36, 37, 41, 43) can be open-collector (200kpps) or line driver (500kpps). For the detailed wiring, please refer to the “Installation and Wiring” chapter of this manual.

Command Source of Pr Position Control Mode

The internal positioning mode, **Pr**, uses the drive's **Internal Indexer** for position control. The command sources of this mode are the 16 registers P1-15 through P1-30, which provide up to eight different command positions. Each command position consists of one register which defines the number of complete motor revolutions (setpoint is entered in motor revolutions), and a second register which defines any fraction of a revolution (setpoint is entered in counts; **each motor revolution is 10,000 counts, or pulses**). Parameter P1-33 selects either Absolute or Incremental position control. Digital inputs (Position Command Select 0, 1, 2) are used to select which preset position will be used as the target. The selected move is initiated by the rising edge of the digital input configured as the Command Trigger.

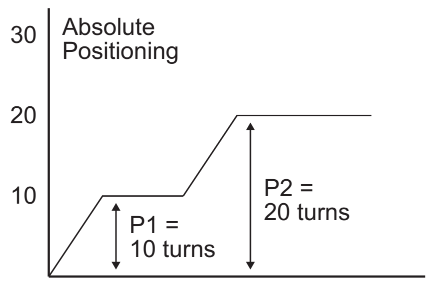
Pr Control Mode Position Command Selection					
Position Command	**DI PCS2**	**DI PCS1**	**DI PCS0**	**Parameters**	**Description**
P1	0	0	0	P1-15	Revolutions (±30,000)
				P1-16	Counts (±10,000)
P2	0	0	1	P1-17	Revolutions (±30,000)
				P1-18	Counts (±10,000)
P3	0	1	0	P1-19	Revolutions (±30,000)
				P1-20	Counts (±10,000)
P4	0	1	1	P1-21	Revolutions (±30,000)
				P1-22	Counts (±10,000)
P5	1	0	0	P1-23	Revolutions (±30,000)
				P1-24	Counts (±10,000)
P6	1	0	1	P1-25	Revolutions (±30,000)
				P1-26	Counts (±10,000)
P7	1	1	0	P1-27	Revolutions (±30,000)
				P1-28	Counts (±10,000)
P8	1	1	1	P1-29	Revolutions (±30,000)
				P1-30	Counts (±10,000)

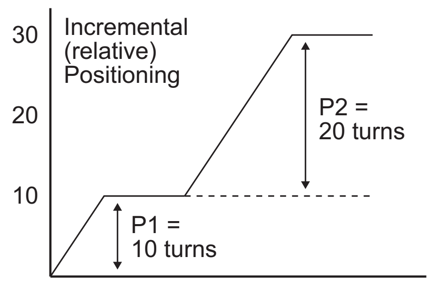
Notes:
1) PCS = Position Command Select DI function; P2-10~P2-17 settings 11~13.
2) Position Command DI status: 0 indicates DI is inactive; 1 indicates DI is active.
3) The position command is activated by an Off to On transition of the Command Trigger DI.

In **Absolute Positioning** (P1-33 = 0), the command positions determine an absolute position for the motor to move to. If P1-15 = 4, and P1-16 = -5000, the motor will proceed to an absolute position of 3½ revolutions regardless of where the motor was previously. (Refer to the Parameters chapter of this manual for further details.) Absolute mode is ideally suited for positioning tables, linear slides, robotics, or other applications where the motor position is always referenced back to a known home position.

In **Incremental Positioning** (P1-33 = 1), the same parameters of P1-15 = 4 and P1-16 = -5000 would cause the motor to move 3½ revolutions from it's current location. Incremental mode is ideal for conveyors, pull belts, or other applications where the motor does not need to be referenced back to a single position: the motor only needs to move a certain distance each cycle.

The difference between absolute and incremental position control is shown on the graphs below. Assume the servo is homed and starts at an actual position of zero (0). The servo is given position commands of 10 revolutions, then 20 revolutions. If the drive is in Absolute Mode, the motor would go to an absolute position of 10 revolutions, then the motor would go to an absolute position of 20 revolutions. In Incremental Mode, the motor would move 10 revolutions, then the motor would move an additional 20 revolutions (ending up a total of 30 revolutions from 0).

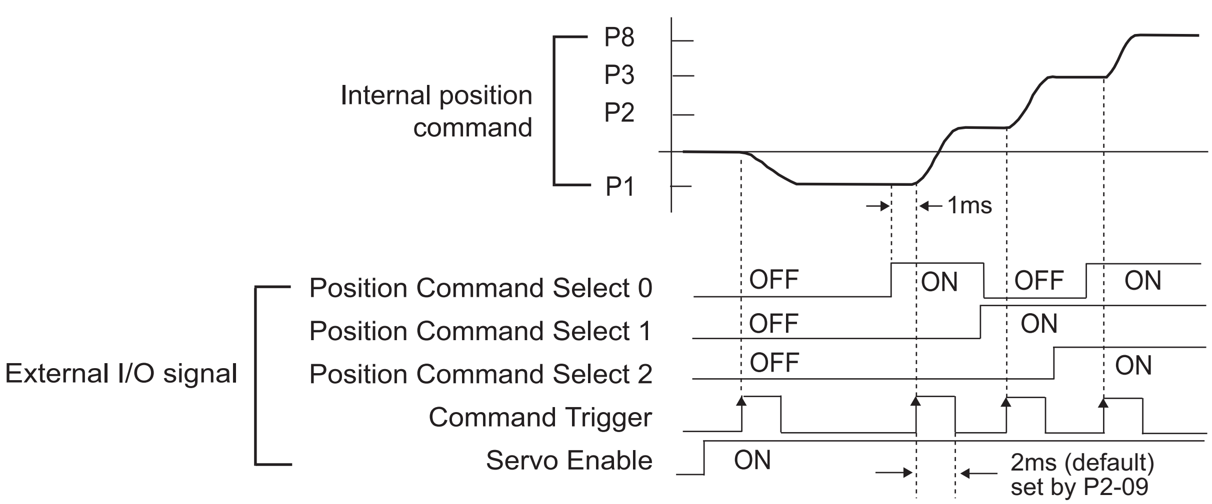




Timing Chart of Pr Position Control Mode

In Pr mode, the position command source is derived from the Digital Input signals from CN1 (Position Command Select 0, 1, and 2, as well as the Command Trigger). The following diagram shows the timing relationship between these DI command signals. The Position Command Select inputs need to be held on for a minimum of 1ms before the Command Trigger input initiates a move.

The Debounce Filter parameter, P2-09, is used to filter electrical noise and prevent false Command Triggers. The more P2-09 is increased, the less susceptible the system is to noise. However, increasing P2-09 too much may filter out intended triggers.



Teach Position Function for Pr Absolute Position Control

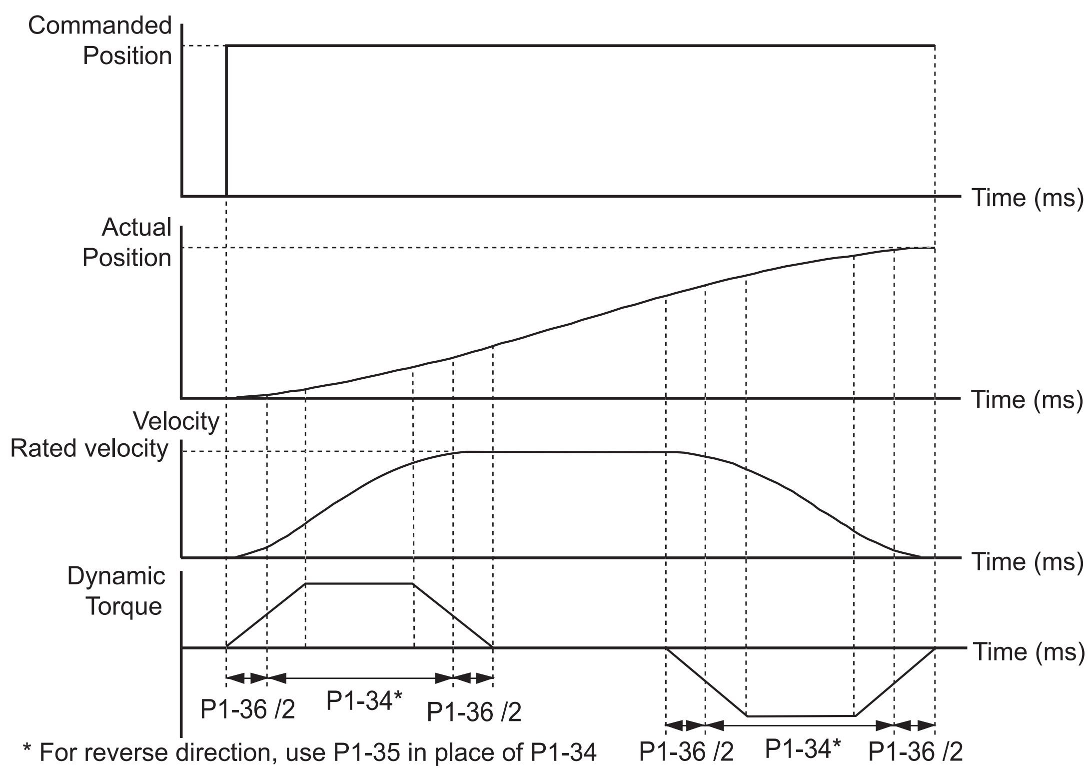
A Teach Position Function is available for use in the Pr Mode with Absolute Positioning. This function allows users to jog the motor to the desired positions and set those positions as the Target Positions. In many cases, this method is easier than entering numeric values directly into P1-15 ~ P1-30. Refer to the "Teach Position Function" subsection of the "Keypad and Display Operation" chapter for more information on the Teach Position Function.

S-curve Filter for Pr Position Control

The S-curve filter smoothes the command position in Pr mode when changing from one position setpoint to another. Since the position commands are not smooth and continuous, the S-curve is set to filter this step response and allow the servo to smoothly transition from one position to another. S-curve is not used in the Pt control mode because the acceleration, deceleration and rate of change is usually handled by the motion controller.

The three parameters used in the S-curve filtering are Acceleration Time (P1-34), Deceleration Time (P1-35), and S-curve Time (P1-36). The relationship between these three settings and how they respond to a step change in command position can be seen in the following graphs. (P1-34 determines both the acceleration and deceleration ramps in the forward direction, and P1-35 determines accel and decel in reverse.)

If P1-36 is set to zero, the S-curve function is disabled, and the filter is bypassed.



S-curve characteristics and Time relationship during Acceleration; Forward Direction*

Parameters for Absolute and Incremental Pr Control (P1-33 = 0,1)

Generally Relevant Parameters

Pr Control Mode Relevant Parameters Absolute and Incremental Positioning (P1-33 = 0, 1)	
Parameter	**Parameter Settings**
P1-01 Control Mode and Output Direction	Settings: 1: Forward = CCW rotation 101: Forward = CW rotation
P1-08 Position Command Low-pass Filter	Setting Range: 0~1000 x10ms
P1-15 ~ P1-30 Position Commands	Setting Ranges: ±30,000 revolutions ±10,000 counts (Refer to separate table below)
P1-33 Position Control Mode	Settings: 0: Absolute Position Mode 1: Incremental Position Mode
P1-34 Acceleration Time	Setting Range: 1~20,000 ms Valid only if P1-36 > 0
P1-35 Deceleration Time	Setting Range: 1~20,000 ms Valid only if P1-36 > 0
P1-36 Acceleration/Deceleration S-curve	Setting Range: 0~10,000 ms P1-34 and P1-35 are disabled when P1-36 = 0
P1-44, P2-60 ~ P2-62 Electronic Gear Numerators	Setting Range: 0~32,767 counts Select which numerator is active using DI (P2-10 ~ P2-17).
P1-45 Electronic Gear Denominator	Setting Range: 0~32,767 counts
P1-47 Homing Mode	Settings: 202: Forward Homing 203: Reverse Homing
P1-50 Home Position Offset (rev)	Setting Range: ±30,000 revolutions
P1-51 Home Position Offset (counts)	Setting Range: ±10,000 counts
P2-10 ~ P2-17 Digital Input Terminals	Settings: 43: Electronic Gear Numerator Selection bit 0 44: Electronic Gear Numerator Selection bit 1
P2-36 ~ P2-43 Position Velocities	Setting Range: 1~5000 rpm (Refer to separate table below)

Positioning Parameters

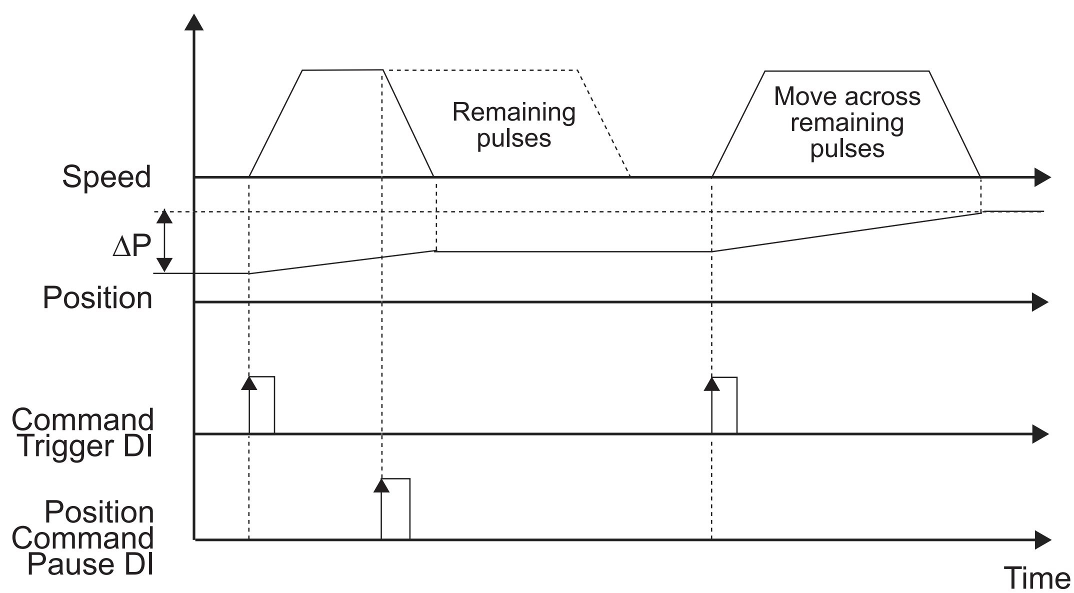
Pr Control Mode Positioning Parameters Absolute and Incremental Positioning (P1-33 = 0, 1)		
Position	**Position Command Parameters**	**Position Velocity Parameter**
1	P1-15 revolutions; P1-16 counts	P2-36
2	P1-17 revolutions; P1-18 counts	P2-37
3	P1-19 revolutions; P1-20 counts	P2-38
4	P1-21 revolutions; P1-22 counts	P2-39
5	P1-23 revolutions; P1-24 counts	P2-40
6	P1-25 revolutions; P1-26 counts	P2-41
7	P1-27 revolutions; P1-28 counts	P2-42
8	P1-29 revolutions; P1-30 counts	P2-43

Trigger Timing Chart for Absolute and Incremental Pr Control

Refer to the "Timing Chart of Pr Position Control Mode" section of this chapter.

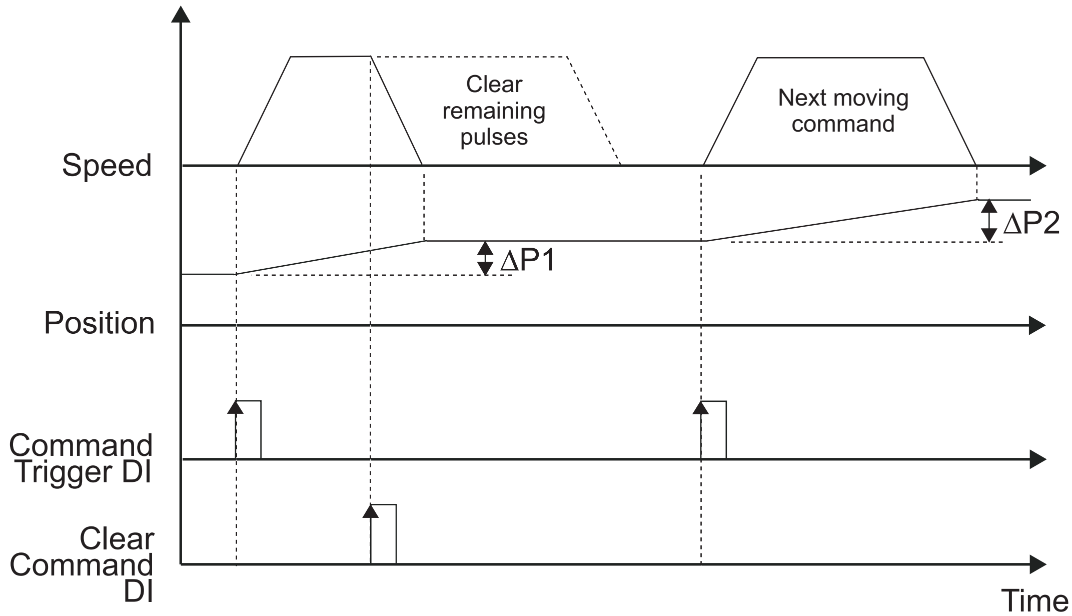
Pause Timing Chart for Absolute and Incremental Pr Control

If the Position Command Pause digital input becomes active while the servo motor is moving, the motor will decelerate and stop according to the deceleration settings of P1-35 and P1-36. When the Command Trigger DI goes active again, the motor will move the remaining number of pulses until it reaches the target position that was previously set.



Clear Timing Chart for Absolute and Incremental Pr Control

This Clear Command feature can be used if P2-50 is set to 2. If the Clear Command digital input becomes active while the servo motor is moving, the motor will decelerate and stop according to the deceleration settings of P1-35 and P1-36. The remaining position pulses will be cleared. When the Command Trigger DI goes active again, the motor will move from it’s present position to the target position that is currently set.



Parameters for Index Mode Pr Control (P1-33 = 2,3,4)

Generally Relevant Parameters for Index Mode Pr Control

Pr Control Mode Relevant Parameters Index Mode Positioning (P1-33 = 2,3,4)	
Parameter	**Parameter Settings**
P1-01 Control Mode and Output Direction	Settings: 1: Forward = CCW rotation 101: Forward = CW rotation
P1-12 Torque Limit 1	Setting Range: ±300 % (In Index Modes, the Torque Limit can be used in combination with the Index Mode Control digital inputs to command a “Torque Decrease” when at an Index Position.)
P1-33 Position Control Mode	Settings: 2: Forward Operation Index Mode 3: Reverse Operation Index Mode 4: Shortest Path Index Mode
P1-34 Acceleration Time	Setting Range: 1~20,000 ms Valid only if P1-36 > 0
Table continued on next page.	

<table>
<tr><th colspan="3">Pr Control Mode Relevant Parameters
Index Mode Positioning (P1-33 = 2,3,4) [continued]</th></tr>
<tr><th>Parameter</th><th colspan="2">Parameter Settings</th></tr>
<tr><td>P1-35
Deceleration Time</td><td colspan="2">Setting Range: 1~20,000 ms
Valid only if P1-36 > 0</td></tr>
<tr><td>P1-36
Acceleration/Deceleration S-curve</td><td colspan="2">Setting Range: 0~10,000 ms
P1-34 and P1-35 are disabled when P1-36 = 0</td></tr>
<tr><td>P1-44
Electronic Gear Numerator</td><td>Setting Range:
0~32,767 counts</td><td rowspan="2">Set the EGR numerator and denominator to the ratio of motor turns per one turn of the load.
Example: If the load table turns once for every 100 turns of the motor, then set P1-44 = 100, and P1-45 = 1.</td></tr>
<tr><td>P1-45
Electronic Gear Denominator</td><td>Setting Range:
0~32,767 counts</td></tr>
<tr><td>P1-47
Homing Mode</td><td colspan="2">Settings:
202: Forward Homing
203: Reverse Homing</td></tr>
<tr><td>P1-50
Home Position Offset (rev)</td><td colspan="2">Setting Range: ±30,000 revolutions</td></tr>
<tr><td>P1-51
Home Position Offset (counts)</td><td colspan="2">Setting Range: ±10,000 counts</td></tr>
<tr><td>P1-55
Maximum Velocity Limit</td><td colspan="2">Setting Ranges:
0~5000 rpm (SVL-2xxx low inertia motors)
0~3000 rpm (SVM-2xxx medium inertia motors)</td></tr>
<tr><td>P2-10 ~ P2-17
Digital Input Terminals</td><td colspan="2">Settings:
(Refer to Digital I/O Parameters table below for Index Mode Selections)</td></tr>
<tr><td>P2-36
Position Velocity</td><td colspan="2">Setting Range: 1~5000 rpm
(If P2-36 > 3000, set P1-55 appropriately)
(This velocity applies to all Indexes.)</td></tr>
<tr><td>P2-44
Digital Output Mode</td><td colspan="2">Settings:
0: Outputs function per P2-18 ~ P2-22
1: Outputs indicate current status during index mode operation
(Refer to DO Signals table below for status indications.)</td></tr>
<tr><td>P2-45
Index Mode Output
Signal Delay Time</td><td colspan="2">Setting Range: 0~250 x4ms
(Applicable only if P2-44 = 1)
(This parameter delays the DO signals.)</td></tr>
<tr><td>P2-46
Index Mode Stations</td><td colspan="2">Setting Range: 2~32 stations
(This parameter determines the total number of index stations on the load table, changer, etc.)</td></tr>
<tr><td>P2-47
Position Deviation
Clear Delay Time</td><td colspan="2">Setting Range: 0~250 x20ms</td></tr>
<tr><td>P2-51
Servo Enable Command</td><td colspan="2">Settings:
0: Servo Enable controlled by DI per P2-10 ~ P2-17
1: Servo Enable is activated when control power is applied to servo
(Recommended in this mode only, because Index Mode Control DI handle Fault Stop function.)</td></tr>
</table>

Digital I/O Parameters for Index Mode Pr Control

Pr Control Mode Digital I/O Parameters Index Mode Positioning (P1-33 = 2,3,4)		
DI Signal	**Parameter Setting**	**Explanation**
DI1	P2-10 = 128	Index Mode Select 0
DI2	P2-11 = 129	Index Mode Select 1
DI3	P2-12 = 130	Index Mode Select 2
DI4	P2-13 = 131	Index Mode Select 3
DI5	P2-14 = 124	Home Sensor
DI6	P2-15 = 101	Servo Enable
	P2-15 = 132	Index Mode Select 4
	P2-15 = 35 (use N.C. contact)	Index Mode - Manual Continuous Operation
	P2-15 = 36 (use N.C. contact)	Index Mode - Manual Single Step Operation
DI7	P2-16 = 33 (use N.C. contact)	Index Mode Control 0
DI8	P2-17 = 34 (use N.C. contact)	Index Mode Control 1
DO Signal	**Parameter Setting**	**Explanation**
DO1	P2-18 = 101	Servo Ready
DO2	P2-19 = 103	At Zero Velocity
DO3	P2-20 = 109	Homing Completed
DO4	P2-21 = 105	At Position
DO5	P2-22 = 107	Active Fault

Functions of Pr Index Mode DI Codes 33, 34, 35,36				
Status	**Manual Index Mode Operation** **Continuous or Single Step** **DI Code 35 or 36**	**Index Mode Control 1** **DI Code 34**	**Index Mode Control 0** **DI Code 33**	**Function**
1	OFF	OFF	OFF	Decrease Torque
2		ON	OFF	Index Mode
3		OFF	ON	Home Position Mode
4		ON	ON	Fault Stop
	ON	x	x	don't care
		ON	OFF	CW manual operation
		OFF	ON	CCW manual operation
		x	x	don't care
Notes:	1) The Fault Stop message will display if DI code 35 or 36 are ON when power is cycled to the drive. If 35 or 36 then go OFF, the Fault Stop message will automatically clear. 2) The Fault Stop message will display when the status is switched directly from 2 to 3, or from 3 to 2. To prevent this situation, switch to status 1 first; i.e. 2 to 1 to 3, or 3 to 1 to 2.			

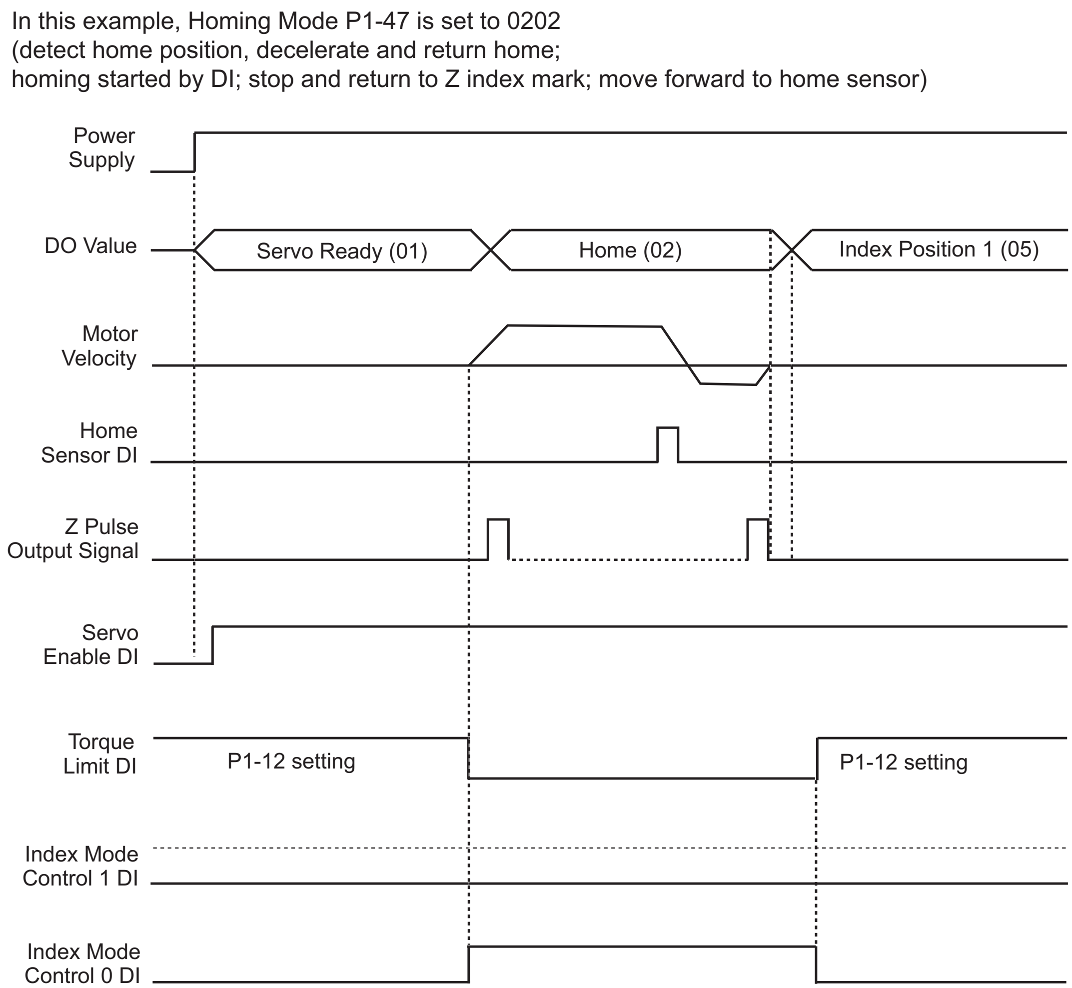
Index Selection Using Pr Index Mode Select DI					
Index Mode Select 4 DI Code 32	Index Mode Select 3 DI Code 31	Index Mode Select 2 DI Code 30	Index Mode Select 1 DI Code 29	Index Mode Select 0 DI Code 28	Index Number
0	0	0	0	0	**1**
0	0	0	0	1	**2**
0	0	0	1	0	**3**
0	0	0	1	1	**4**
0	0	1	0	0	**5**
0	0	1	0	1	**6**
0	0	1	1	0	**7**
0	0	1	1	1	**8**
0	1	0	0	0	**9**
0	1	0	0	1	**10**
0	1	0	1	0	**11**
0	1	0	1	1	**12**
0	1	1	0	0	**13**
0	1	1	0	1	**14**
0	1	1	1	0	**15**
0	1	1	1	1	**16**
1	0	0	0	0	**17**
1	0	0	0	1	**18**
1	0	0	1	0	**19**
1	0	0	1	1	**20**
1	0	1	0	0	**21**
1	0	1	0	1	**22**
1	0	1	1	0	**23**
1	0	1	1	1	**24**
1	1	0	0	0	**25**
1	1	0	0	1	**26**
1	1	0	1	0	**27**
1	1	0	1	1	**28**
1	1	1	0	0	**29**
1	1	1	0	1	**30**
1	1	1	1	0	**31**
1	1	1	1	1	**32**
0 = open ; 1 = closed					-

Pr Index Mode Indications of DO Signals						
#	DO5	DO4	DO3	DO2	DO1	DO Indication
0	0	0	0	0	0	Alarm
1	0	0	0	0	1	Servo Ready
2	0	0	0	1	0	Homing Operation in Progress
3	0	0	0	1	1	Home Operation Completed
4	0	0	1	0	0	Index Position Change in Progress
5	0	0	1	0	1	Index Position 1 Attained
6	0	0	1	1	0	Index Position 2 Attained
7	0	0	1	1	1	Index Position 3 Attained
8	0	1	0	0	0	Index Position 4 Attained
9	0	1	0	0	1	Index Position 5 Attained
10	0	1	0	1	0	Index Position 6 Attained
11	0	1	0	1	1	Index Position 7 Attained
12	0	1	1	0	0	Index Position 8 Attained
13	0	1	1	0	1	Index Position 9 Attained
14	0	1	1	1	0	Index Position 10 Attained
15	0	1	1	1	1	Index Position 11 Attained
16	1	0	0	0	0	Index Position 12 Attained
17	1	0	0	0	1	Index Position 13 Attained
18	1	0	0	1	0	Index Position 14 Attained
19	1	0	0	1	1	Index Position 15 Attained
20	1	0	1	0	0	Index Position 16 Attained
21	1	0	1	0	1	Index Position 17 Attained
22	1	0	1	1	0	Index Position 18 Attained
23	1	0	1	1	1	Index Position 19 Attained
24	1	1	0	0	0	Index Position 20 Attained
25	1	1	0	0	1	Index Position 21 Attained
26	1	1	0	1	0	Index Position 22 Attained
27	1	1	0	1	1	Index Position 23 Attained
28	1	1	1	0	0	Index Position 24 Attained
29	1	1	1	0	1	Index Position 25 Attained
30	1	1	1	1	0	Index Position 26 Attained
31	1	1	1	1	1	Index Position 27 Attained
-	0 = open ; 1 = closed					-

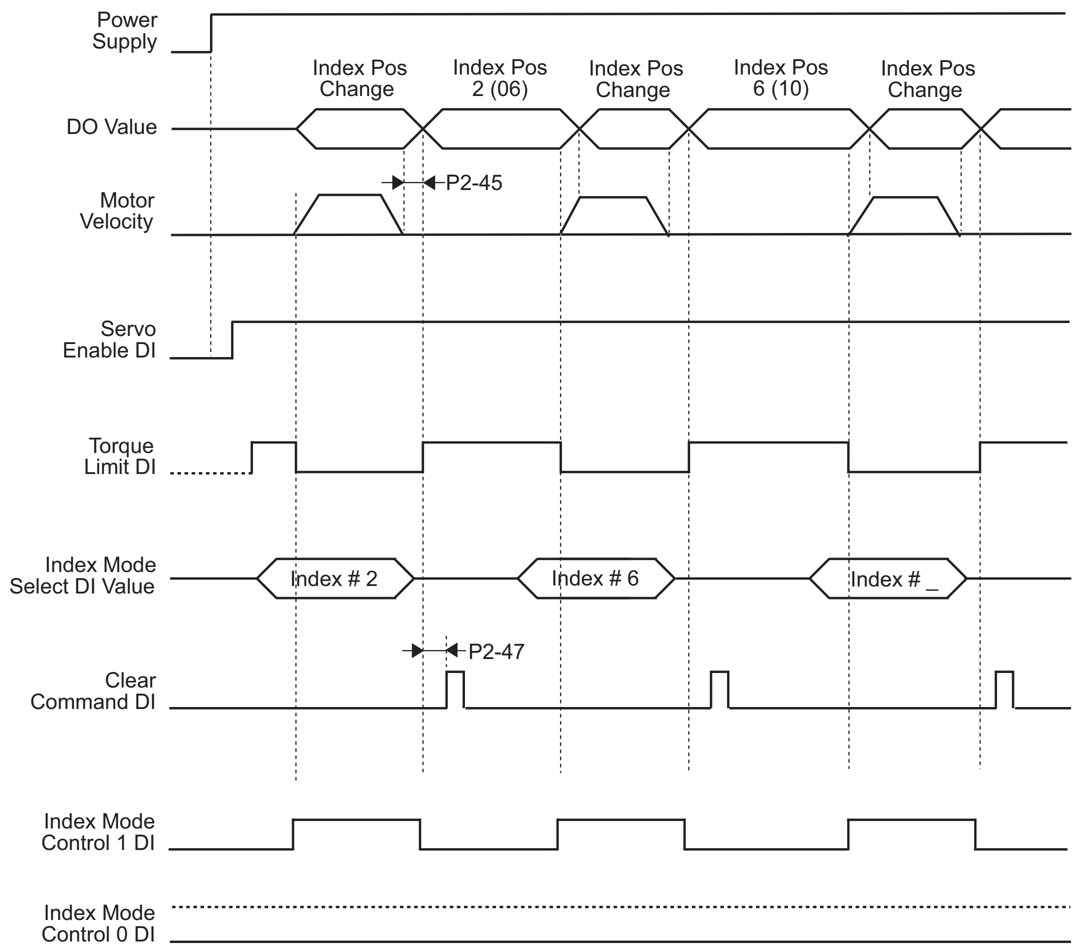
If the DO indication switches to Servo Ready (DO = 1) during a Homing operation, remove any abnormal conditions and then re-Home to ensure that the Home position is correct.

Timing Charts of Pr Index Mode DI/DO Signals Operation

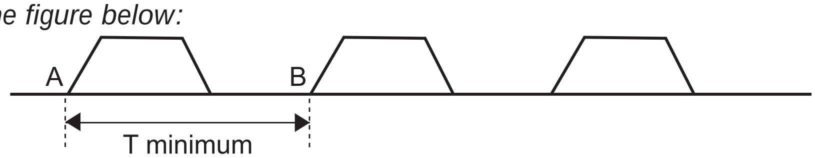
Pr Index Mode Home Search Timing Chart



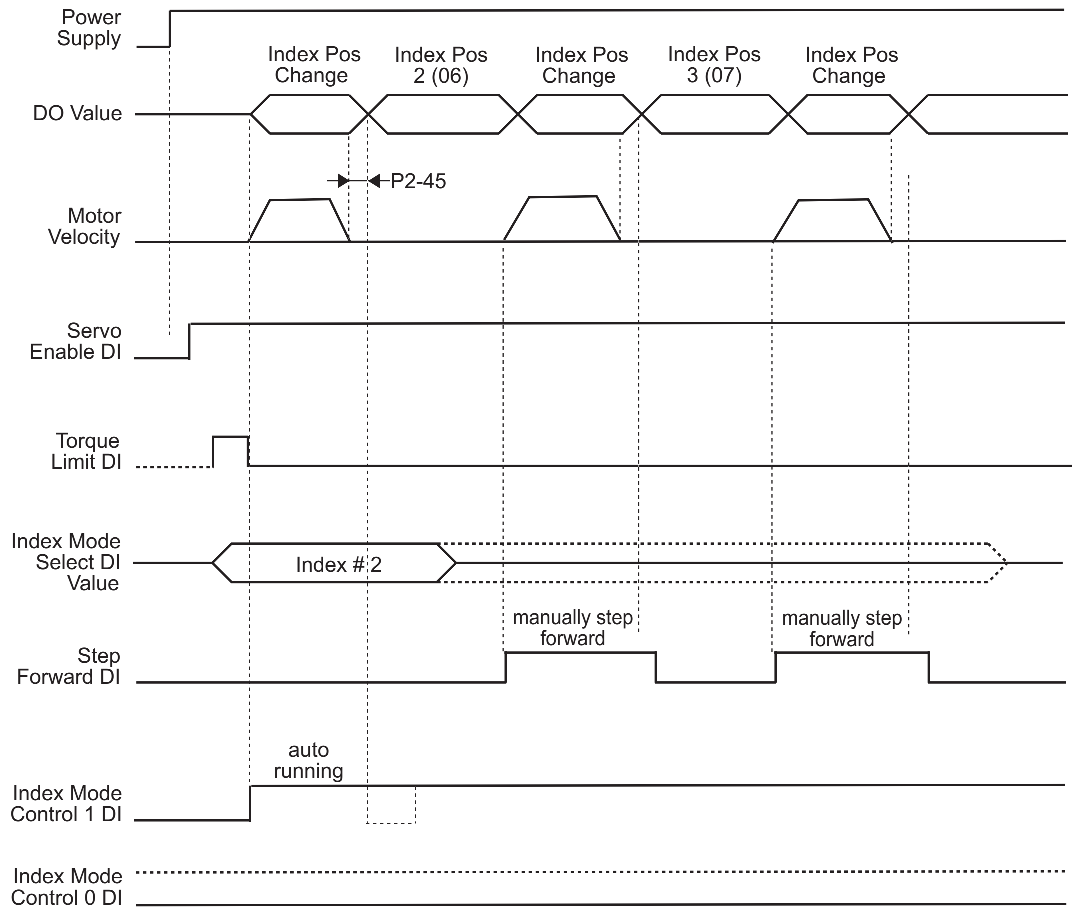
Pr Index Mode Timing Chart using Clear Command DI



The maximum value of P2-45 = 125 x $T_{minimum}$, where $T_{minimum}$ is the minimum time from A to B, i.e. starting to run at A and starting to run at B. (Time unit is 1 sec.) Refer to the figure below:

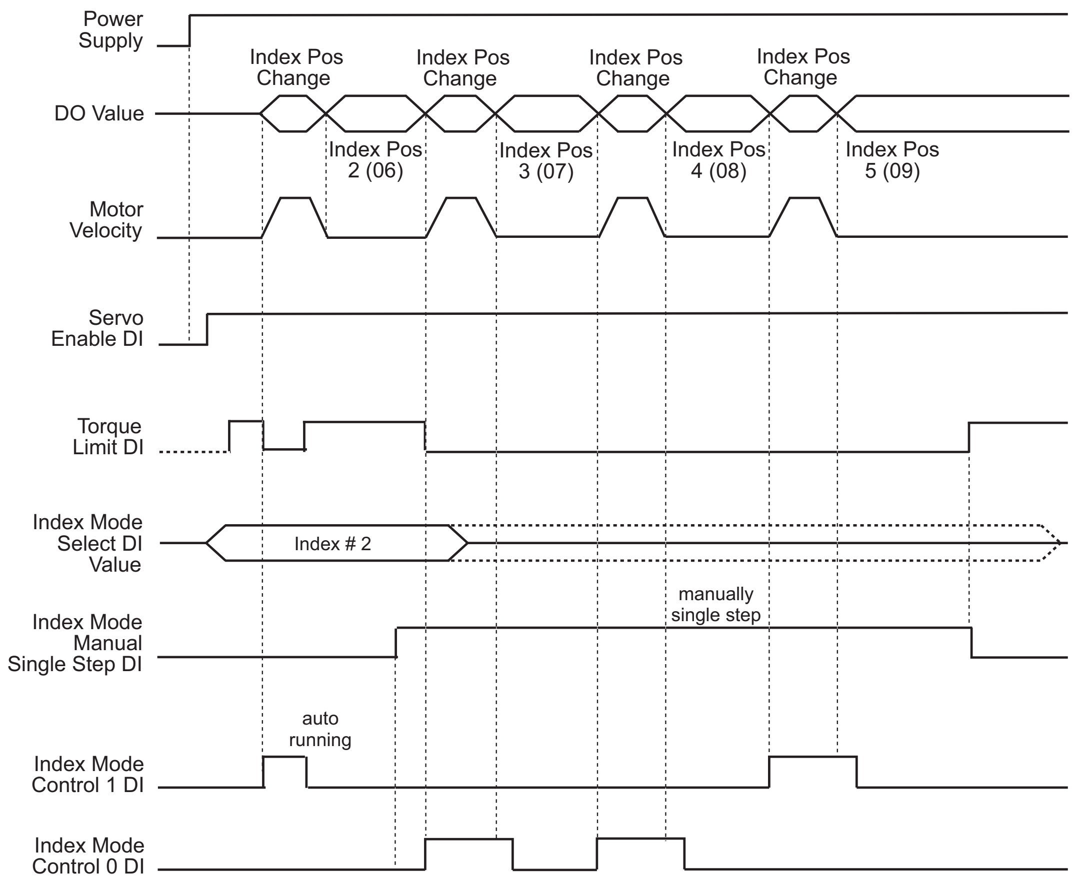


Pr Index Manual Mode Timing Chart using Step Forward DI



1) The manual step forward velocity is set by parameter P2-36.
2) Set the Index Mode Control 1 DI ON before using the Step Forward DI to initiate the move. The Index Mode Select DI should remain unchanged to prevent returning to Index # 1 when the Step Forward operation occurs.

Pr Index Manual Mode Timing Chart using Manual Single Step DI

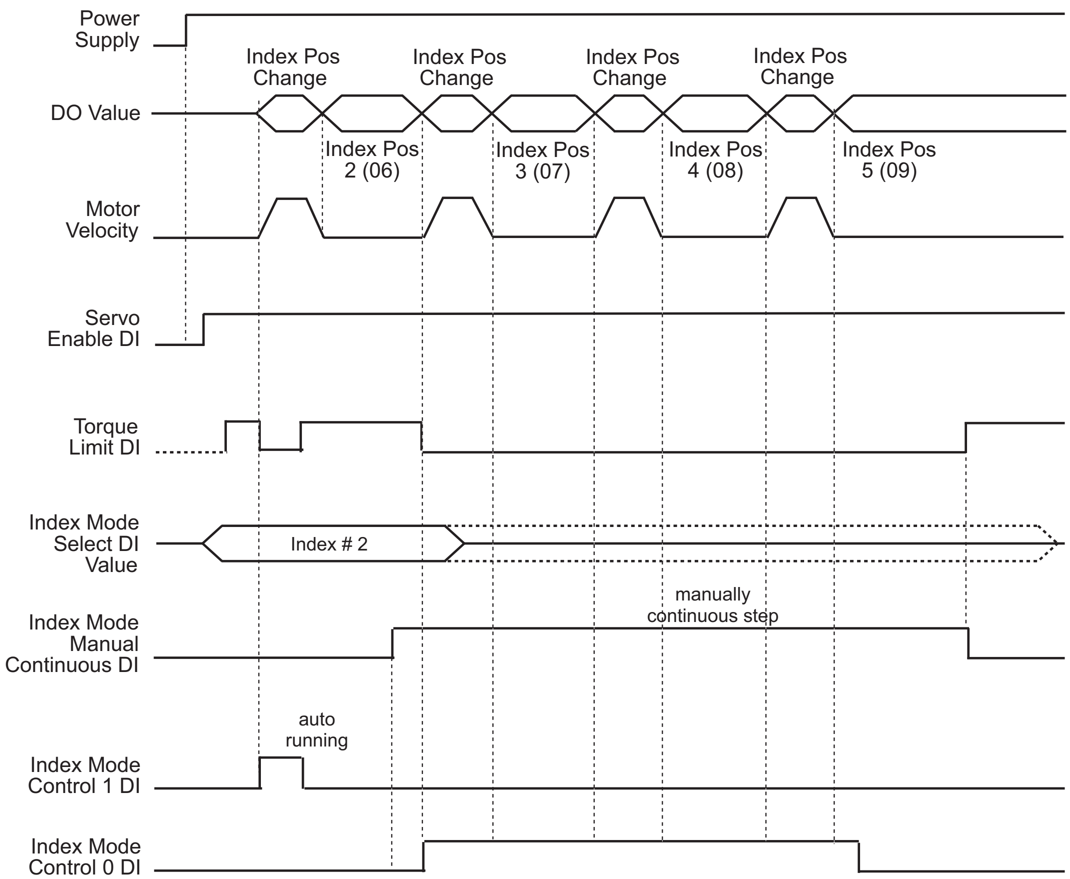


The manual single step velocity is set by parameter P2-36.

When the Index Mode Manual Single Step DI is ON, the rising edge of the Index Mode Control 0 DI will initiate a forward single step, and a rising edge of the Index Mode Control 1 DI will initiate a reverse single step.

To prevent abnormal conditions, follow this procedure after the single step operation is completed:
1) Turn the Index Mode Control 0 and 1 DI OFF.
2) Then cycle the Index Mode Manual Single Step DI from ON to OFF

Pr Index Manual Mode Timing Chart using Manual Continuous DI



The manual continuous operation velocity is set by parameter P2-36.

When the Index Mode Manual Continuous Operation DI is ON, the servo motor will continuously operate forward while the Index Mode Control 0 DI is ON, and will continuously operate in reverse while the Index Mode Control 1 DI is ON.

To prevent abnormal conditions, follow this procedure after the manual continuous operation is completed:
1) Turn the Index Mode Control 0 and 1 DI OFF.
2) Then cycle the Index Mode Manual Continuous Operation DI from ON to OFF

Parameters for Absolute and Incremental Auto Pr Control (P1-33 = 5,6)

Internal Absolute and Incremental Auto Position Modes allow the *Sure*Servo Drive to be easily programmed to step through a series of eight unique indexes (moves). They are the same indexes available in the standard Pr mode (Parameters P1-15 ~ P1-30). In normal Pr mode (P1-33 = 00 or 01), a controller must select each individual index through a binary combination of Digital Inputs. In Auto Index Position Mode (P1-33 = 05 or 06), the drive will step itself through a series of indexes (moves). Each index can be triggered either by Digital Inputs (Step Forward or Step Reverse), or can be set to automatically start a set period of time after the preceding index has completed. Auto Position Mode is ideal for applications where the sequence of motions for the servo will not change. (The actual command positions can be changed via Modbus).

The following instructions assume some familiarity with the *Sure*Servo system. Please read the rest of this chapter and the QuickStart Guide (Appendix A) before attempting to program the drive for Auto Position Control.

Warning: **Always start any new servo setup with the motor shaft disconnected from the load. This could possibly save machinery or personnel from serious damage. DISCONNECT THE LOAD. Always wire an E-Stop circuit into the power feed for the drive. DO NOT rely on the Fault Stop digital input. Always disconnect the main incoming power for emergency stop conditions. (Control power can remain ON.)**

Instructions for Absolute and Incremental Auto Position Control

1) Set P2-08 to 10. This will reset the drive to factory defaults.
2) Cycle power.
3) Set P1-31 to the correct motor code.
4) Set P1-33 to the correct Position Control Mode.
   P1-33 = 5; Absolute Auto Position Mode
   P1-33 = 6; Incremental Auto Position Mode
5) Set P1-01 to the correct Control Mode.
   P1-01 = 00001; Pr Position Control Mode (command setpoints via internal registers)
6) Set the parameters for position, velocity, and dwell time. The position setpoints will either be incremental distances or absolute positions depending on the setting of P1-33. The velocity setpoints correspond to the appropriate indexes. The accompanying dwell times determine how many milliseconds will elapse between each move while the Step Forward and Step Reverse commands are constantly being issued, or when the Auto Indexing (continuous steps) Mode is selected. If the dwell time for any individual move is 0ms, that move will be bypassed in the sequence of operations.

Pr Control Mode Positioning Parameters Absolute and Incremental Auto Positioning (P1-33 = 5, 6)			
Position	**Position Command Parameters**	**Position Velocity Parameter**	**Dwell Time Parameter (x10ms)**
Index 1	P1-15 revolutions; P1-16 counts	P2-36	P2-52
Index 2	P1-17 revolutions; P1-18 counts	P2-37	P2-53
Index 3	P1-19 revolutions; P1-20 counts	P2-38	P2-54
Index 4	P1-21 revolutions; P1-22 counts	P2-39	P2-55
Index 5	P1-23 revolutions; P1-24 counts	P2-40	P2-56
Index 6	P1-25 revolutions; P1-26 counts	P2-41	P2-57
Index 7	P1-27 revolutions; P1-28 counts	P2-42	P2-58
Index 8	P1-29 revolutions; P1-30 counts	P2-43	P2-59

7) Set P1-34, P1-35, P1-36 for Acceleration, Deceleration, and S-curve. Without setting these parameters, the drive may fault when a move is first intitiated. Acceleration and Deceleration are ignored unless the S-Curve parameter is set to a non-zero amount.

P1-36 defaults to 0 when the drive is set to factory defaults. Without changing this parameter setting, the drive may fault when movement is initiated (a value of zero assumes instantaneous acceleration and deceleration).

8) Configure the Digital Inputs. Define the following functions for your inputs. (The following table is an example only. See the Parameters chapter for more information on changing the inputs' definitions and states [normally open vs. normally closed]).

Pr Control Mode DI Function Parameters Absolute and Incremental Auto Positioning (P1-33 = 5, 6)			
Digital Input	**DI Function Parameter**	**Parameter Setting**	**Function Description**
DI1	P2-10	124	Home Sensor
DI2	P2-11	121	Fault Stop
DI3	P2-12	0	Input Disabled
DI4	P2-13	127	Start Home Move Trigger
DI5	P2-14	140	Step Forward
DI6	P2-15	142	Auto Position Mode
DI7	P2-16	139	Step Reverse
DI8	P2-17	101	Servo Enable

9) Set P2-44, Digital Output Mode, to the desired setting. A value of 00 sets the Digital Outputs to function according to the settings in P2-18 ~ P2-22. A value of 01 sets the Digital Outputs to indicate the current position during index mode operation. They will generate the following binary code as status for an external controller. This is useful to check to see that the servo has arrived at the appropriate index point. This binary code is shown in P4-09, and can also be read via Modbus. (Refer to the “MODBUS Communications” chapter of this manual for information regarding Modbus communication.)

Pr Control Mode DO Signals Indications Parameters Absolute and Incremental Auto Positioning (P1-33 = 5, 6)						
#	**DO5**	**DO4**	**DO3**	**DO2**	**DO1**	**DO Indication**
0	0	0	0	0	0	Alarm
1	0	0	0	0	1	Servo Ready
2	0	0	0	1	0	Homing Operation in Progress
3	0	0	0	1	1	Home Operation Completed
4	0	0	1	0	0	Index Position Change in Progress
5	0	0	1	0	1	Index Position 1 Attained
6	0	0	1	1	0	Index Position 2 Attained
7	0	0	1	1	1	Index Position 3 Attained
8	0	1	0	0	0	Index Position 4 Attained
9	0	1	0	0	1	Index Position 5 Attained
10	0	1	0	1	0	Index Position 6 Attained
11	0	1	0	1	1	Index Position 7 Attained
12	0	1	1	0	0	Index Position 8 Attained
-	0 = open ; 1 = closed					-

10) Configure P1-47, Homing Mode (if necessary). The drive will automatically power up at position zero. If your application needs a homing reference, see P1-47 for configuration. A value of 0202 in P1-47 will configure the drive to look for an external home command signal. When the Home Sensor Digital Input is triggered, the drive will search for an external (DI) Home Sensor. When the home sensor is found, the drive will reverse and proceed to the next motor encoder Z-pulse. Your application may vary.

P1-47 = 0202; Home to sensor when home command is issued.

11) Cycle power to the drive. This will allow all changes to take effect. The drive will now follow Step Forward/Step Reverse Commands and the Start Home Move Trigger Command.

When the drive is in Absolute Auto Position Mode (using absolute references for command position), the drive will not Step Reverse to zero position unless Position Command 1 (P1-15 and P1-16) is equal to zero.

An anomaly may occur when not all indexes are programmed (ie: Dwell Times = 0ms in P2-59, etc.). If the master controller (PLC) commands a Step Forward past the last valid position, the master controller will have to issue two Step Reverse commands before movement will occur. (Trying to Step past a valid Step 8 does not cause this anomaly; only one Step Reverse will initiate motion.)

Do not issue JOG or Home commands while Step Forward, Step Reverse, or Auto Index Position motions are occurring. The drive will halt the current move and immediately begin the commanded Jogging or Homing.

Command and Response Example for Absolute and Incremental Auto Pr Control

When in Internal (Pr) Auto Position Control Mode, the outputs can set to output a binary code to an external controller (PLC, etc.) Setting P2-44 to 1 will cause the outputs to follow the binary code shown previously. When in this state, the external controller can monitor the status of the *Sure*Servo Drive, not only for faults, but also for the position of the motor. The following is an example of the state of the drive outputs when P2-44 = 1. This can be monitored via DI signals going to an external controller's inputs, or can be read via Modbus from parameter P4-09; Modbus hex address 0x0409 ("1033" in 0-based Modbus addressing, "41034" in 1-based Modbus addressing).

This example is for Absolute Auto Position Mode (P1-33 = 5). All Indexes represent an absolute command position for the drive to go to. If using Incremental Auto Position Mode (P1.33 = 6), all Indexes will be lengths of moves. All other logic remains the same.

Example: Absolute and Incremental Pr Auto Positioning	
Action or Status	**P4-09 (DO Status) Value**
Drive is in Fault condition	0 - Alarm
Drive is powered up with no Faults	1 - Servo Ready
Start Home Move Trigger DI is triggered; homing sequence begins	2 - Homing Operation in Progress
Home sequence completes	3 - Home Operation Completed
Return to Index 1 DI is triggered; move begins from Home to Index Position 1	4 - Index Position Change in Progress
Motor arrives at Index Position 1	5 - Index Position 1 Attained
Step Forward DI is triggered; move begins to Index Position 2	4 - Index Position Change in Progress
Motor arrives at Index Position 2	6 - Index Position 2 Attained
Step Forward DI is triggered; move begins to Index Position 3	4 - Index Position Change in Progress
Motor arrives at Index Position 3	7 - Index Position 3 Attained
Step Reverse DI is triggered; move begins to Index Position 2	4 - Index Position Change in Progress
Motor arrives at Index Position 2	6 - Index Position 2 Attained
Step Reverse DI is triggered; move begins to Index Position 1	4 - Index Position Change in Progress
Motor arrives at Index Position 1	5 - Index Position 1 Attained

With this type of response behavior, it is very simple for a PLC to accurately maintain the drive status and motor location; even if no communication (Modbus, etc.) is available in the PLC. The DO (digital outputs) will relay the drive status (faulted, moving, current position, etc.). Remember, if any of the dwell times are zero, the corresponding index will be invalid (it will be skipped by the internal sequencer whenever STEP FWD, STEP REV, or Auto Index Mode are active).

If running Auto Index Mode, the sequence of events when Auto Index Position Mode DI is ON will be Index 1, Dwell Time 1, Index 2, Dwell Time 2, ….Index 7, Dwell Time 7, Index 8, Dwell Time 8, Index 1, Dwell Time 1, Index 2, Dwell Time 2, etc.

If running Step FWD/Step REV, then Stepping FWD past Index 8 will result in no motion. Stepping Rev past Index 1 also will result in no motion.

Velocity Control Mode

The Velocity Control modes (V and Vz) are used on applications of precision speed control, such as CNC machines, conveyor speed matching, etc. Typically, the command signal is generated from an analog motion controller (a CNC controller, for example), or from a speed sensing device (when matching one conveyor speed to another, etc.). The *Sure*Servo drive supports two kinds of command sources in Velocity Control mode; (1) external analog ±10Vdc signal and (2) internal velocity parameters.

The V mode (external) allows the user to select either the analog signal or one of three internal velocity settings. The Vz mode (internal) allows only the use of internal setpoints for velocity commands (a command of zero, plus three velocity setpoints). Both Velocity modes use two Digital Inputs to select which velocity command (analog and/or preset) is active.

In order for the *Sure*Servo motor and load to operate smoothly, the servo drive provides complete S-curve profiling in velocity control mode. The *Sure*Servo drive provides closed loop gain adjustment and an integrated PI controller. Also, the servo drive provides three modes of tuning technology (Manual/Auto/Easy).

Command Source of Velocity Control Mode

Velocity command sources:

1) External analog signal; external analog voltage input, -10V to +10V.
2) Internal parameter: P1-09 to P1-11.

Velocity Control Mode Command Source							
Velocity Command	**DI Signal**		**Command Source**			**Content**	**Range**
	[1]VCS1(15)	**[1]VCS0(14)**					
Velocity #1	0	0	Mode	V	[2] External AI	Voltage V_{ref} to GND	±10V
				Vz	Zero Velocity	Velocity Command is 0	0
Velocity #2	0	1	Internal parameters			P1-09	±5000 rpm
Velocity #3	1	0				P1-10	±5000 rpm
Velocity #4	1	1				P1-11	±5000 rpm

Note 1: VCS = "Velocity Command Select" DI function; P2-10~P2-17 settings 14 (VCS0) and 15 (VCS1).

Note 2: When using AI velocity command, set P4-22 (Analog Velocity Input Offset) to trim the signal so that a 0V command results in no motor rotation.

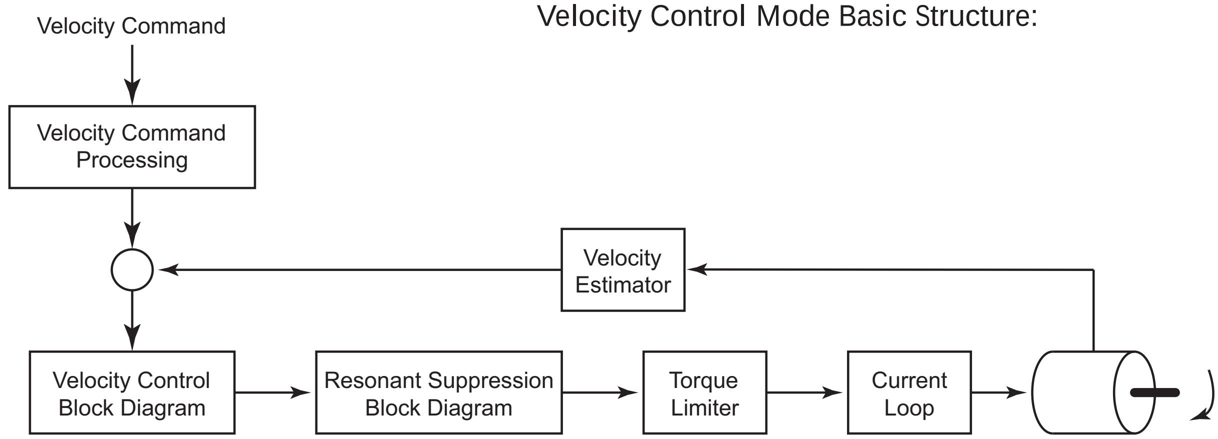
If the Velocity Command Select digital inputs (VCS0 and VCS1) are both = 0, and the control mode of operation is Vz, then the velocity command is 0. Therefore, if users do not need to use analog voltage as a velocity command, they can choose Vz mode and avoid the zero point drift problem of analog voltage signals. If the current control mode of operation is V, then the command is the analog voltage between V-REF and GND. The setting range of the input voltage is from -10V to +10V and the corresponding rotation velocity is adjustable (see parameter P1-40).

When at least one of the Velocity Command Select inputs is enabled, the velocity command is the corresponding internal parameter shown in the table above. The command is valid (enabled) immediately after either VCS0 or VCS1 is changed. It is not necessary to trigger the Command Trigger digital input (as in Pr mode).

Note: The velocity commands are used as the velocity limit commands in the Torque Control modes (T or Tz mode).

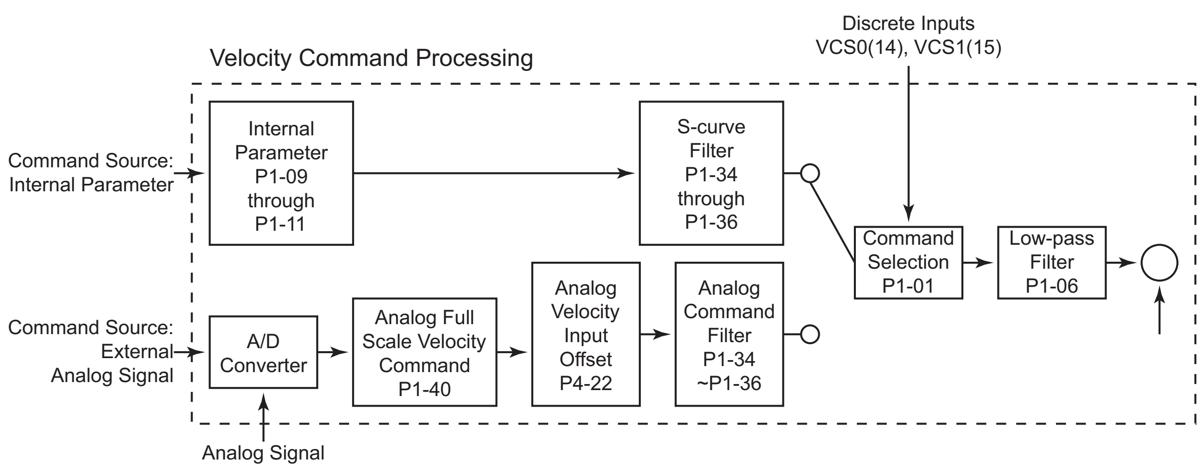
Structure of Velocity Control Mode

Velocity Control Mode Basic Structure:



In the figure above, the velocity command processing is used to select the command source of velocity control, including maximum rotation speed of analog velocity command selection (parameter P1-40) and S-curve filter of velocity control. The velocity control block diagram is used to manage the gain parameters of the servo drive, and to calculate the current input supplied to the servo motor. The resonance suppression block diagram is used to suppress the resonance of mechanical system.

The function and structure of velocity command processing is shown as the figure below:



The command source is selected according to the state of VCS0, VCS1 and parameter P1-01 (V or Vz). The S-curve and low-pass filters smooth the transition from one velocity setpoint to another.

Smoothing Strategy of Velocity Control Mode

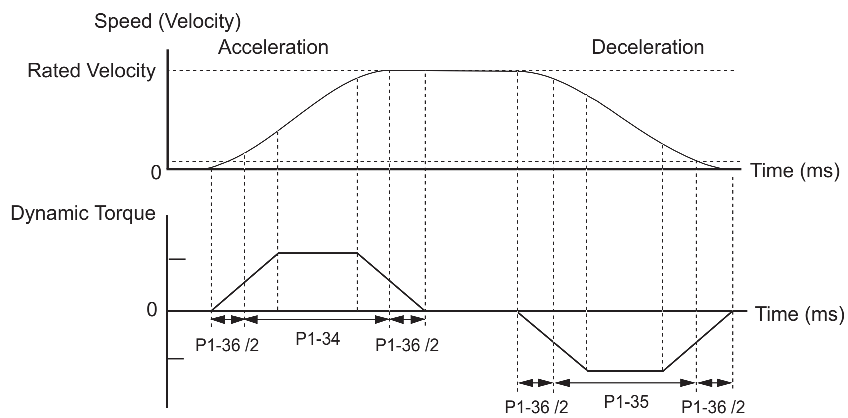
S-curve Filter and Analog Command Filter

The **S-curve Filter** is a combination of three parameters that can smooth the effects of sudden changes in velocity when a new internal Velocity Command is selected. Using the S-curve filter allows a more gradual output response to sudden command changes. This reduces the mechanical resonance and noise that would otherwise be caused by friction and inertia during sudden velocity changes, and improves the servo motor performance during acceleration, operation, and deceleration.

The parameters that compose the S-curve filter are the Accel/Decel S-curve constant (P1-36), Acceleration Time constant (P1-34), and Deceleration Time constant (P1-35).

If P1-36 is set to zero, the Accel/Decel S-curve function is disabled.

S-curve Characteristics and Time Relationship



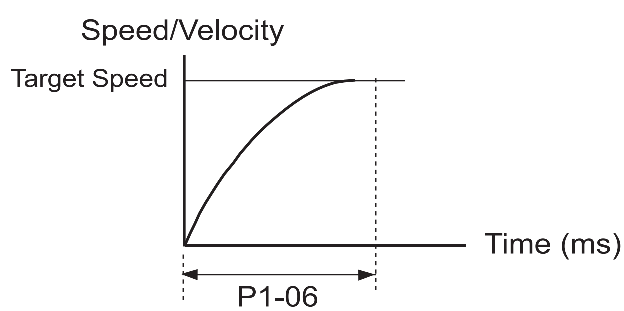
S-curve Characteristics and Time Relationship

Analog Velocity Command Low-pass Filter (AVCLF)

The Analog Velocity Command Low-pass Filter is used to eliminate high frequency response and electrical interference from the analog input signal, and it smoothes the output response regardless of whether the command source is internal or external. The AVCLF consists of the same three parameters as does the S-curve Filter (P1-34, P1-35, P1-36), and also functions similarly to the S-curve Filter.

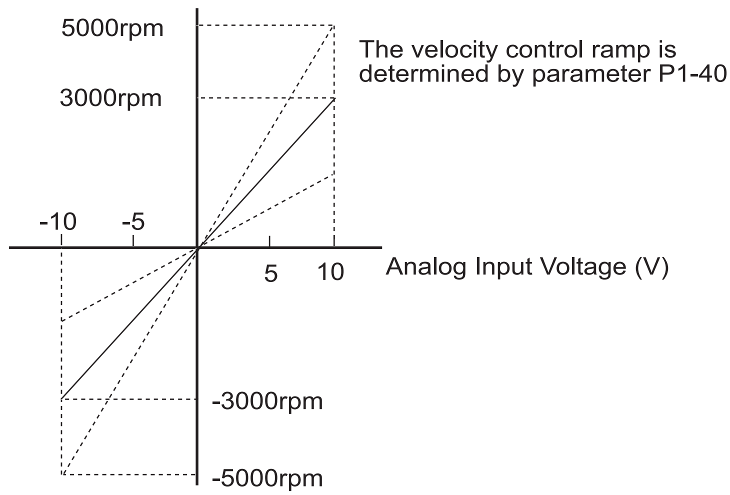
If P1-06 is set to zero (0), the Analog Velocity Command Low-pass Filter is disabled.

The P1-06 filter smoothes the output response from internal parameter and from analog input command sources.



Analog Velocity Input Scaling

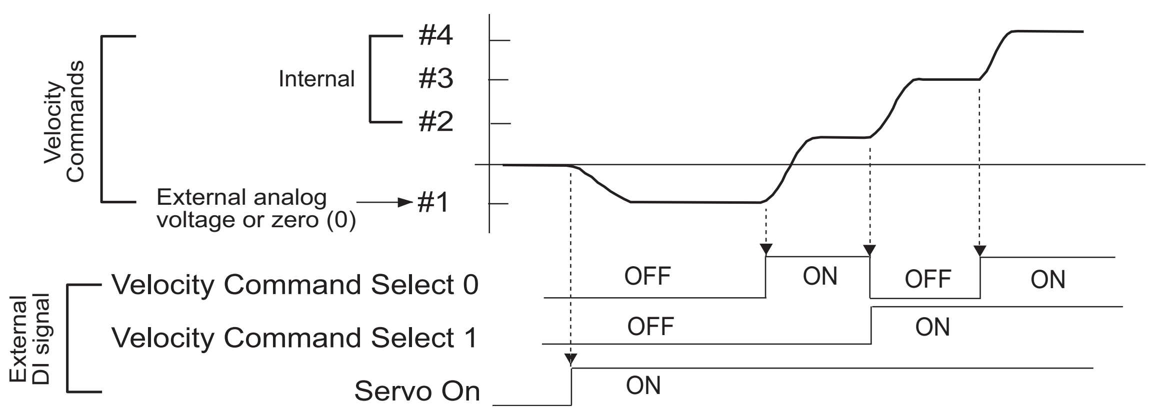
The analog voltage between V_REF (analog Velocity Command input) and GND (CN1 pins 12, 13, 19, 44) determines the motor Velocity Command. Parameter P1-40 (Analog Full Scale Velocity Command/Limit) adjusts the velocity control range and the slope of its ramp. For example, when P1-40 is set to 3000, the maximum rotation speed of the analog velocity command (10V) is 3000 rpm, as shown below.



- Velocity Command = ((P1-40)/10) [(Input V) - ((P4-22)/1000)]; Limit ±(P1-40)

P4-22 (Analog Velocity Input Offset) can be used to establish an offset so that zero velocity does not occur at zero input voltage. A 0~10V input can be used for bidirectional control.

Timing Chart of Velocity Control Mode

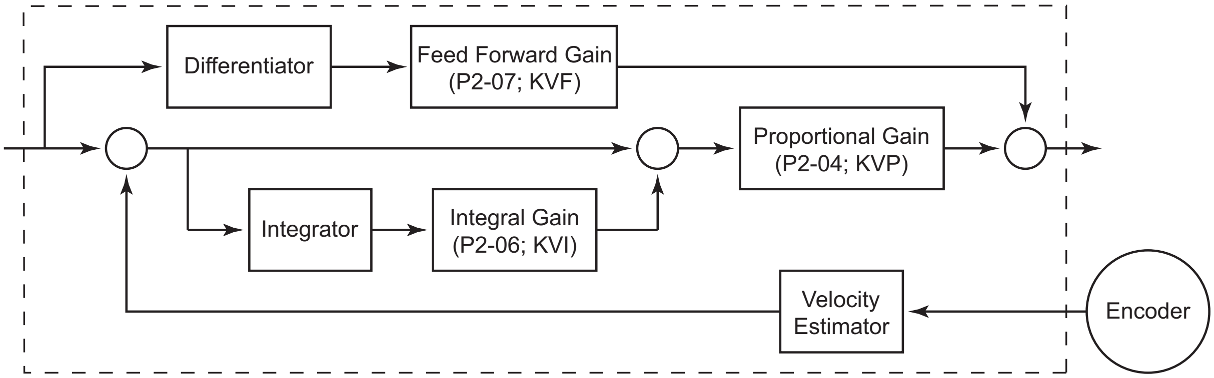


1) When Velocity Control Mode is Vz, the velocity command #1=0.
2) When velocity control mode is V, the velocity command #1 is external analog voltage input.

Velocity Loop Gain Adjustment

The function and structure of velocity control mode is shown below:

Velocity Control Block Diagram

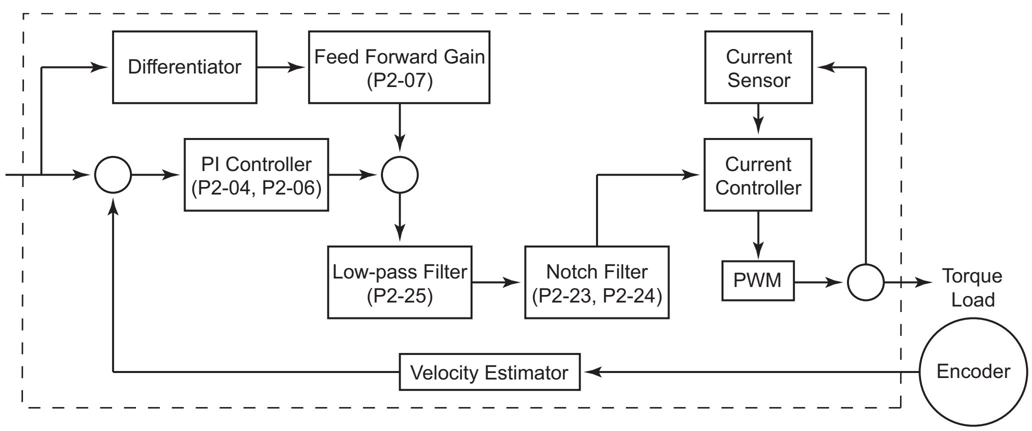


The gain of *Sure*Servo drives can be adjusted using any one of three tuning modes: 1) Manual, 2) Auto, or 3) Easy. Refer to the "Tuning Modes" section of this chapter for more details on these tuning modes.

Resonance Suppression

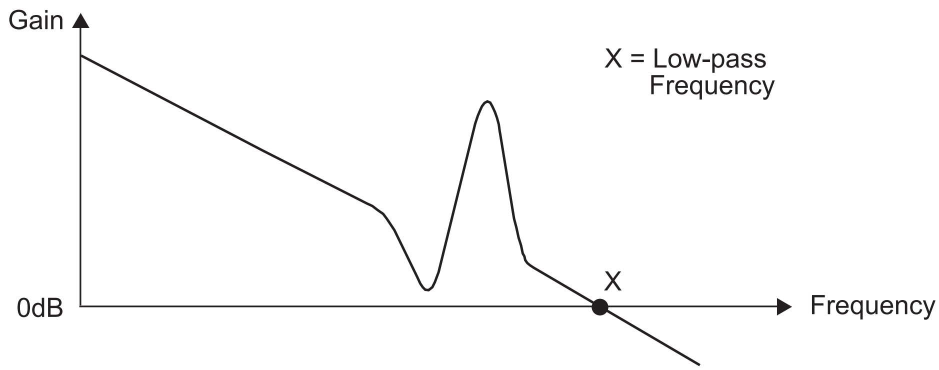
Resonance of the mechanical system may occur due to excessive system stiffness or frequency response. However, this kind of resonance condition can be improved, suppressed, or even eliminated by using the Low-pass Filter (P2-25) and the Notch Filter (P2-23 & P2-24).

Resonance Suppression Block Diagram

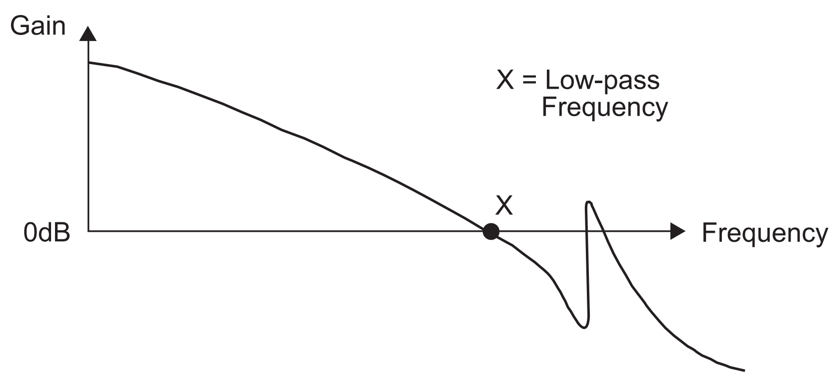


Low-pass Filter

The Low-pass Filter reduces resonance effects which can cause motor vibration. The figure below shows the resonant open loop gain.



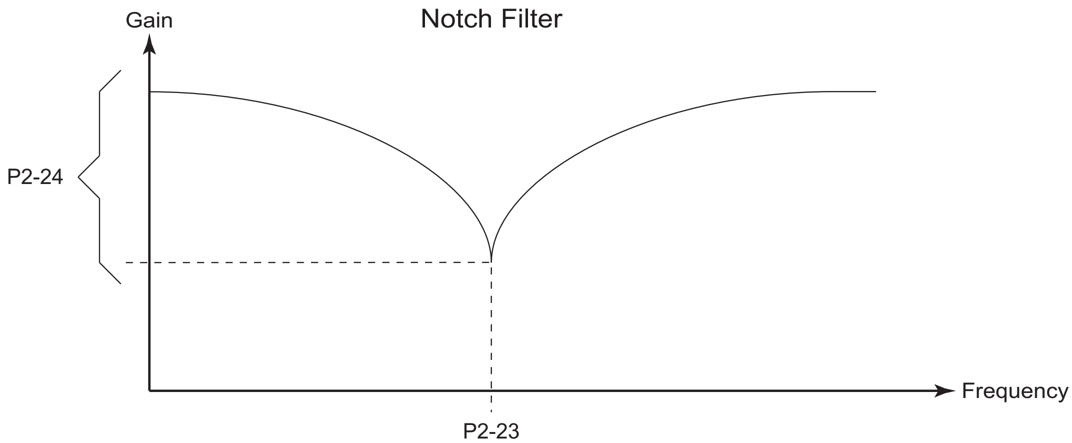
The Low-pass Filter eliminates any response from frequencies above the low-pass frequency. Since the low-pass frequency (X) is inversely proportional to the Low-pass Filter (parameter P2-25), the value of X becomes smaller as P2-25 is increased (see the figure below). The vibration causing resonant condition improves; however, the frequency response and phase margin decrease.



Notch Filter

If the resonant frequency can be determined, then use the Notch Filter (parameters P2-23 & P2-24) to eliminate the resonance, and reduce motor vibration. However, if the resonant frequency is outside of the Notch Filter range (50~1000Hz & 0~32dB), then use the Low-pass Filter to improve the resonance.

To use the Notch Filter, first determine the resonant frequency of the system, and then set P2-23 to that frequency. Then adjust P2-24 upward until resonance is suppressed.



P2-24 should be adjusted only as high as needed to suppress the resonance. An excessive attenuation setting will result in degraded system performance.

Torque Control Mode

The Torque Control Modes (T or Tz) are useful for applications of torque control, such as printing machines, spinning machines, twisters, etc. The *Sure*Servo drive supports two types of command sources in the Torque Control mode: (1) external analog signal, and (2) internal parameters. The external analog signal is from an external voltage input on the CN1 connector, and the internal parameters are P1-12 through P1-14.

Command Source of Torque Control Mode

Torque command Source:

1) External analog signal: External analog voltage input, -10V to +10V.
2) Internal parameter: P1-12 through P1-14.

Selection of the torque command source is determined by the CN1 connector digital inputs that are configured as “Torque Command Select 0” (TCS0) and “Torque Command Select 1” (TCS1) as shown below:

Torque Control Mode Command Source

Torque Command	DI Signal		Command Source			Content	Range
	[1] TCS1(17)	[1] TCS0(16)					
Torque #1	0	0	Mode	T	[2] External AI	Voltage T_{ref} to GND	±10V
				Tz	None	Torque Command is 0	0
Torque #2	0	1	Internal parameters			P1-12	±300%
Torque #3	1	0				P1-13	±300%
Torque #4	1	1				P1-14	±300%

Note 1: TCS = “Torque Command Select” DI function; P2-10~P2-17 settings 16 (TCS0) and 17 (TCS1).

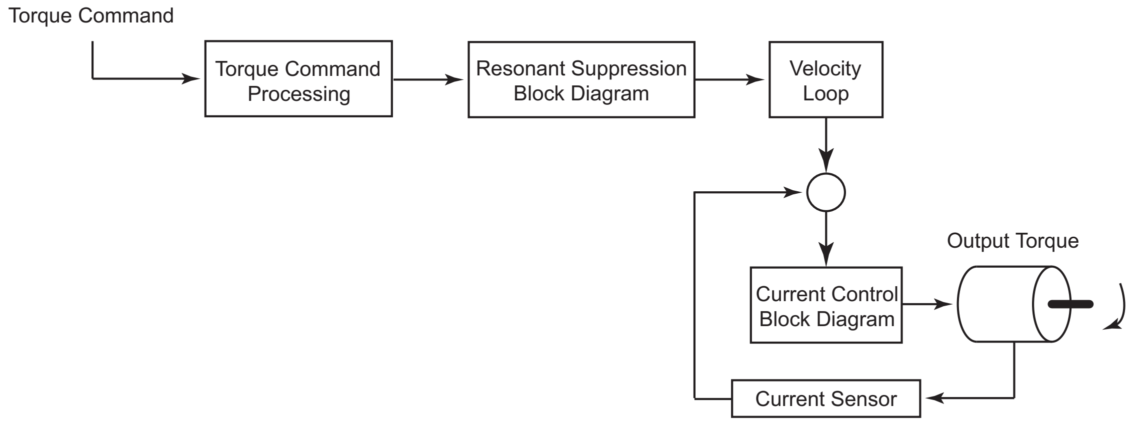
Note 2: When using AI torque command, set P4-23 (Analog Torque Input Offset) to trim the signal so that a 0V command results in no motor rotation.

If TCS0=TCS1=0 (OFF), and the control mode is Tz, then the torque command is zero. Therefore, if the analog voltage input is not to be used as the torque command, then the Tz control mode can be used to avoid the zero point drift problem with analog voltage signals. If TCS0 = TCS1 = 0, and the control mode is T, then the torque command is the analog voltage between the T_REF analog input and GND (CN1 pins 12, 13, 19, 44). The setting range of the input voltage is from -10V to +10V, and the corresponding torque is adjustable using parameter P1-41.

1) *When TCS0 and TCS1 change, the new torque command takes affect immediately.*
2) *The P1-12~P1-14 Torque Commands are used as Torque Limit commands in both position and velocity control modes (Pr, Pt, V, and Vz).*

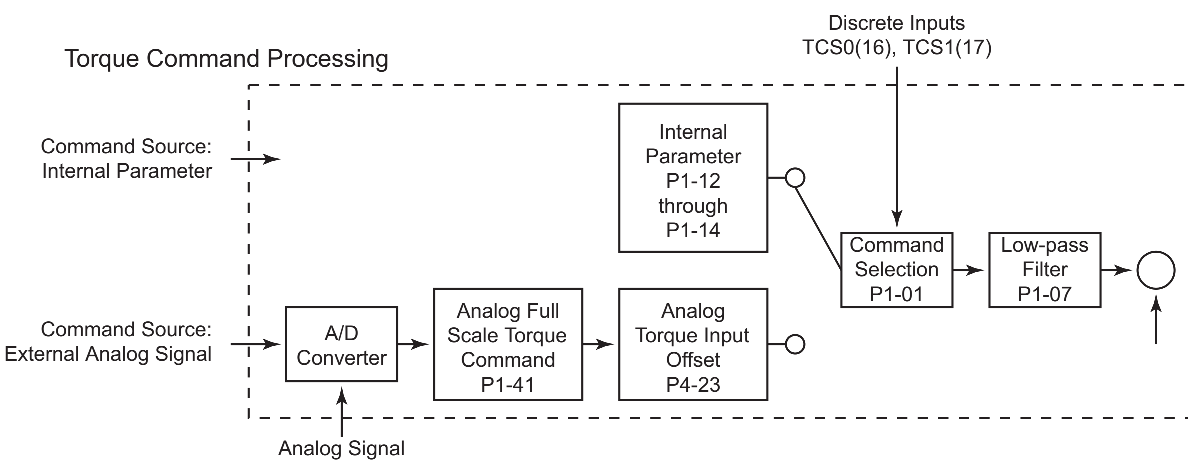
Structure of Torque Control Mode

Basic Structure:



In the figure above, the Torque Command processor is used to select the command source of torque control as described in the previous and following sections, including the Analog Full Scale Torque Command (P1-41), and the smoothing strategy of the torque control mode. The current control block diagram is used to manage the gain parameters of the servo drive and to instantaneously calculate the current input provided to motor.

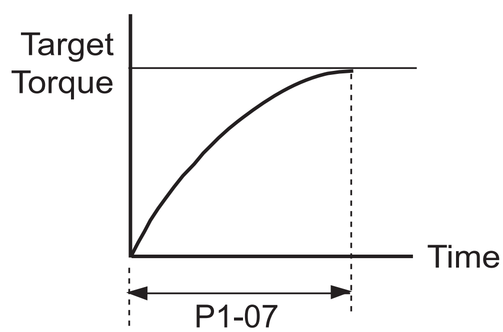
The function and structure of torque command processing is shown below:



Smoothing Strategy of Torque Control Mode

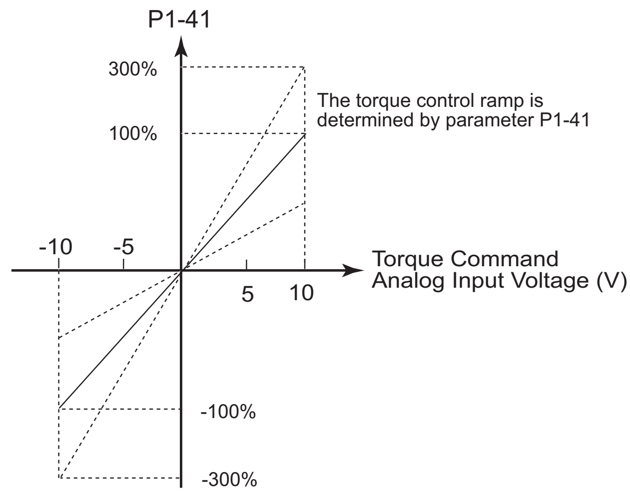
The P1-07 Analog Torque Command Low-pass Filter smoothes the incoming analog torque command.

If P1-07 is set to zero, the smoothing function is disabled.



Analog Torque Input Scaling

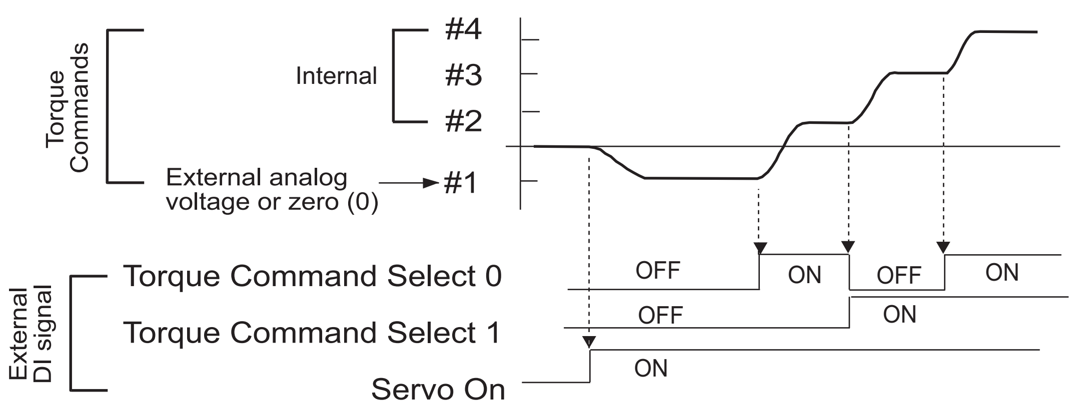
The analog voltage between the T_REF terminal (analog Torque Command input) and GND (CN1 pins 12, 13, 19, 44) determines the motor Torque Command. Parameter P1-41 (Analog Full Scale Torque Command/Limit) adjusts the torque control ramp and its range. For example, when P1-41 is set to 100, the maximum torque of the analog torque command (10V) is 100% of rated torque, as shown below. If the input voltage decreases to 5V, then the analog torque command decreases to 50% of rated torque.



- Torque Command = ((P1-41)/10) [(Input V) - ((P4-23)/1000)]; Limit ±(P1-41)

P4-23 (Analog Torque Input Offset) can be used to establish an offset so that zero torque does not occur at zero input voltage. A 0~10V input can be used for bidirectional control.

Timing Chart of Torque Control Mode



1) When Torque Control Mode is Tz, the torque command #1=0.
2) When Torque Control Mode is T, the torque command #1 is external analog voltage input.

Dual Control Modes Selection

The dual control modes allow *Sure*Servo systems to switch between pre-determined control modes while the servo is enabled. For example, if an application requires both Velocity control and Torque control, P1-01 can be set to 10 to allow a digital input to select between these two control modes. The available dual modes are shown below:

Selection of Dual Control Modes				
	Modes Available	P1-01 Setting	DI Setting P2-10~P2-17	Description
Dual Mode	Pt-V	06	18	Either V or Pt control mode selected by DI (0=V; 1=Pt)
	Pt-T	07	20	Either T or Pt control mode selected by DI (0=T; 1=Pt)
	Pr-V	08	18	Either V or Pr control mode selected by DI (0=V; 1=Pr)
	Pr-T	09	20	Either T or Pr control mode selected by DI (0=T; 1=Pr)
	V-T	10	19	Either V or T control mode selected by DI (0=V; 1=T)
Note: If a digital input is not configured for the Mode Select function, the default mode (0) in each dual mode will be used.				

Position / Velocity Control Mode Selection

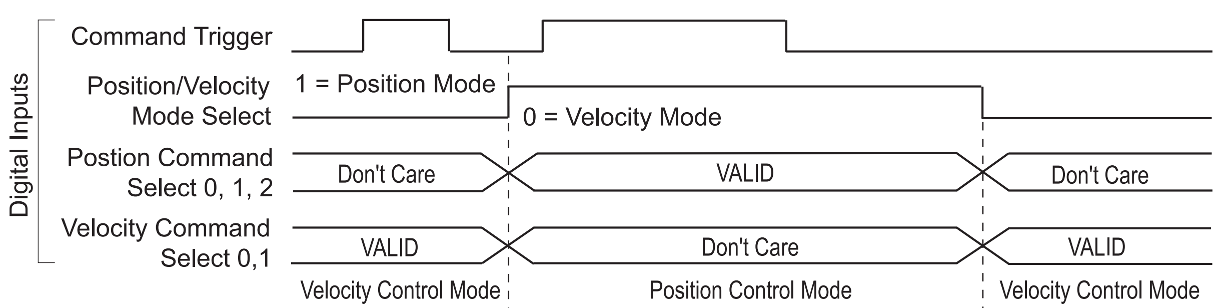
Pt-V Mode / Pr-V Mode:

The command source of Pt-V mode is defined from external digital inputs. The command source of Pr-V mode is from the internal Position Command parameters P1-15 through P1-30. The velocity command can be the external analog voltage input (AI) or the internal Velocity Command parameters P1-09 to P1-11.

The velocity and position mode switching is controlled by the Position/Velocity Mode Select (PVMS) DI signal. The selection will be more complicated when the position of Pr-V mode and velocity command are both selected through DI signals.

The timing chart of position/velocity control mode selection is shown below:

Position / Velocity Mode Selection



When the PVMS DI is OFF, the drive is in Velocity Mode. The velocity command is then selected by the Velocity Command Select DI, and the Command Trigger is ignored.

When the PVMS DI switches to ON, the drive switches to Position Mode. In this mode, the position command is not determined until there is a rising edge of the Command Trigger DI, so the motor stops running. When the drive receives a rising edge of the Command Trigger DI, the Position Command is selected by the Position Command Select DI, and the motor immediately moves to the determined position.

When the PVMS DI switches back to OFF, the drive immediately switches back to Velocity Mode. For more information regarding the relationships between the DI signals and selected commands in each mode, refer to the particular single mode sections of this chapter.

Position / Torque Control Mode Selection

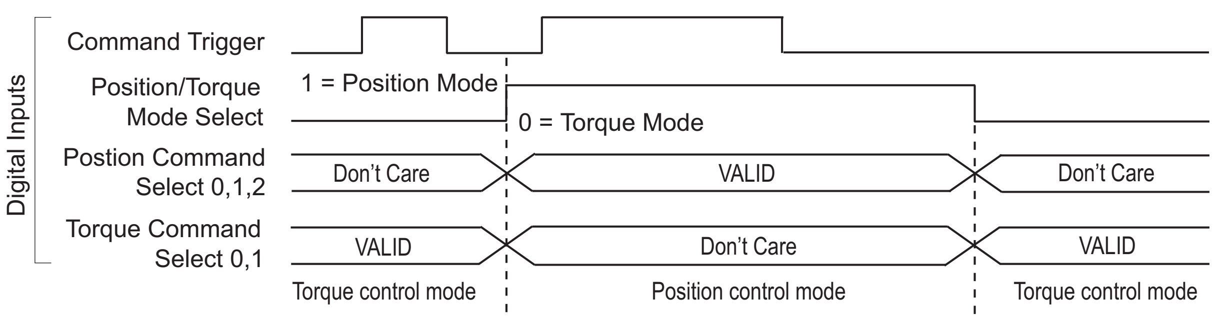
Pt-T Mode / Pr-T Mode:

The position command source of Pt-T mode is from external digital inputs. The position command source of Pr-T mode is from the internal Position Command parameters P1-15 through P1-30. In both modes, the torque command can be the external analog Torque Command signal, or the internal Torque Command parameters P1-12 through P1-14.

The position and torque mode switching is controlled by the Position/Torque Mode Select (PTMS) DI signal. The selection will be more complicated when the position of Pr-T mode and torque command are both selected through DI signals.

The timing chart of position/torque control mode selection is shown below:

Pr Position / Torque Control Mode Selection



When the PTMS DI is OFF, the drive is in Torque Mode. The torque command is then selected by the Torque Command Select DI, and the Command Trigger is disabled.

When the PTMS DI switches to ON, the drive switches to Position Mode. In Pr-T mode, the position command is not determined until there is a rising edge of the Command Trigger DI, so the motor stops running. When the drive receives a rising edge of the Command Trigger DI, the Position Command is selected by the Position Command Select DI, and the motor immediately moves to the determined position. In the Pt-T mode, the drive immediately responds to any high speed pulse inputs.

When the PTMS DI switches back to OFF, the drive immediately switches back to Torque Mode. For more information regarding the relationships between the DI signals and selected commands in each mode, refer to the particular single mode sections of this chapter.

Velocity / Torque Control Mode Selection

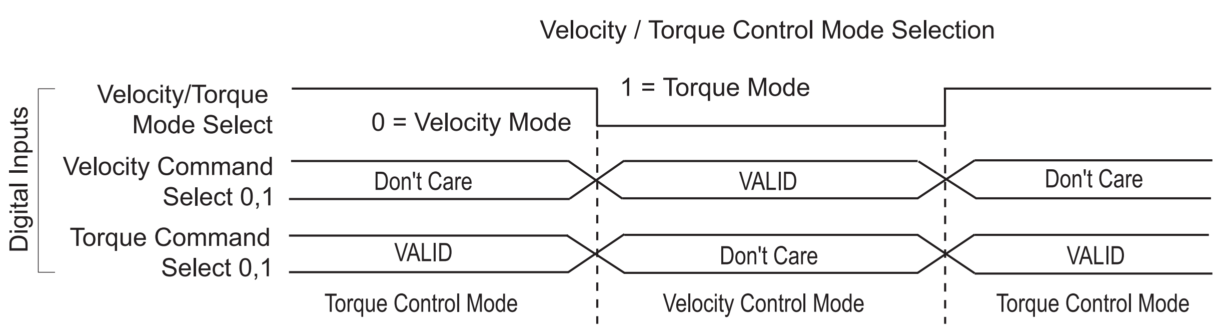
V-T Mode:

In the Velocity Mode, the velocity command can be the external analog voltage input (AI), or it can be the internal Velocity Command parameters (P1-09 to P1-11) combined with the Velocity Command Select DI.

Similarly, in the Torque Mode, the torque command can be the external analog voltage input (AI), or it can be the internal Torque Command parameters (P1-12 to P1-14) combined with the Torque Command Select DI.

The Velocity/Torque Mode Select (VTMS) DI switches the drive between the velocity and torque modes.

The timing chart of velocity/torque control mode selection is shown below:



When the VTMS DI is ON, the drive is in Torque Mode, and the torque command is then selected by the Torque Command Select DI.

When the VTMS DI switches to OFF, the drive switches to Velocity Mode. In this mode, the velocity command is selected by the Velocity Command Select DI, and the motor rotates immediately following the command.

When the VTMS DI switches to back to ON, the drive immediately switches back to Torque Mode. For more information regarding the relationships between the DI signals and selected commands in each mode, refer to the particular single mode sections of this chapter.

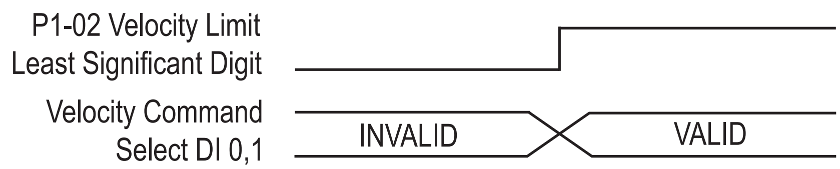
Limits

Velocity Limit

The maximum velocity can be limited by using parameter P1-55 (Maximum Velocity Limit) in ALL control modes.

The velocity limit only can be used in torque mode (T mode) to limit the servo motor velocity. When the torque command is the external analog voltage input, there should be surplus DI signals that can be configured as Velocity Command Select inputs used to select Velocity Limits (P1-09~P1-11). If there are not enough DI signals, then the external voltage input can be used as Velocity Limit. When the setting value of the least significant digit in P1-02 is set to 1, the Velocity Limit function is activated.

The timing chart of Velocity Limit is shown below:

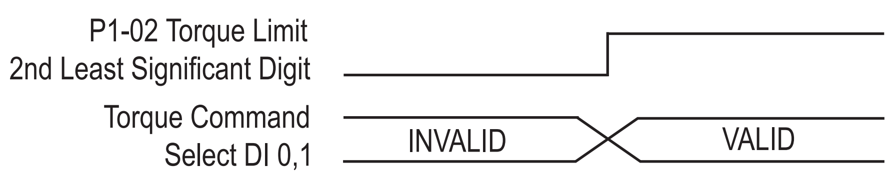


Command Source Selection of Velocity Limit

Torque Limit

The torque limit only can be used in Position Mode (Pt and Pr modes) and Velocity Mode (V mode) to limit the output torque of the servo motor. When the position and velocity commands are the external analog voltage input, there should be surplus DI signals that can be configured as Torque Command Select inputs used to select Torque Limits (P1-12~P1-14). If there are not enough DI signals, then the external voltage analog input can be used as Torque Limit. When the setting value of the second least significant digit in P1-02 is set to 1, the Torque Limit function is activated.

The timing chart of Torque Limit is shown below:



Command Source Selection of Torque Limit

Regenerative Resistor

Built-in Regenerative Resistor

At the point where the load starts driving the servo motor, instead of vice-versa, the motor becomes a generator instead of a motor. The servo systems needs to dissipate the extra energy that is being generated, and it does that through a regenerative resistor. *Sure*Servo drives provide a built-in regenerative resistor, and have the capability to connect an external resistor in case more regenerative capacity is needed.

The following table shows the specifications of the servo drive's built-in regenerative resistor and the amount of regenerative power (average value) that it can process.

Built-in Regenerative Resistor Specifications				
Drive Model	Resistance (Ohm) [Set P1-52]	Capacity (Watt) [Set P1-53]	Regenerative Power * (Watt)	Min. Allowable Resistance (Ohm)
SVA-2040	40	60	30	20
SVA-2100	40	60	30	20
SVA-2300	20	120	60	10
** Regenerative Power Calculation: The amount of regenerative power (average value) that can be processed is rated at 50% of the capacity of the servo drive's built-in regenerative resistor. The regenerative power calculation method of external regenerative resistor is the same.*				

External Regenerative Resistor

When the regenerative power exceeds the processing capacity of the servo drive, install an external regenerative resistor. Please pay close attention on the following notes when using a regenerative resistor:

1) External resistors are available from AutomationDirect. Refer to next page for part #s.

2) Confirm that the settings of resistance (P1-52) and capacity (P1-53) are set correctly.

3) When installing an external regenerative resistor, ensure that its resistance value is the same as the resistance of built-in regenerative resistor. If combining multiple small-capacity regenerative resistors in parallel to increase the regenerative resistor capacity, make sure that the parallel resistance value of the regenerative resistors complies with the specifications listed in the table above.

WARNING: In general, when the amount of regenerative power (average value) that can be processed is used at or below the rated load ratio, the resistance temperature will increase to 120°C or higher (on condition that when the regeneration continuously occurred). For safety reasons, forced air cooling is good way to reduce the temperature of the regenerative resistors. We also recommend that you use regenerative resistors with thermal switches. For the load characteristics of the regenerative resistors, please check with the manufacturer.

External Regenerative Resistor (continued)

When using an external regenerative resistor, connect it to drive terminals P and C, and make sure that the circuit between P and D is open. (Refer to the "Installation and Wiring" chapter for basic wiring diagrams.) Use an external regenerative resistor that meets the specifications in the "Built-in Regenerative Resistor Specifications" table.

External Resistor Method Without Load:

Select the adequate regenerative resistors according to the allowable frequency required by actual operation, and the allowable frequency when the system is run without a load. The allowable frequency when the system is run without a load is the maximum number of times per minute during continuous operation that the servo motor can accelerate from a stop to rated speed and then decelerate back down to a stop. The allowable frequencies when the system is run without a load are summarized in the following table:

Allowable Frequencies for Servo Motor Running Without Load	
Drive Model	**Frequency of Accel & Decel Cycles (times/min)**
SVA-2040	1071
SVA-2100	140
SVA-2300	63

Select the adequate regenerative resistors according to the allowable frequencies by referring to the table below:

Allowable Frequencies for Servo Motor Running Without Load When Using External Regenerative Resistor		
Drive Model	**Automation Direct External Resistor**	**Frequency of Accel & Decel Cycles (times/min)**
SVA-2040	GS-25P0-BR	2247
SVA-2100	GS-2010-BR-ENC	1014
SVA-2300	GS-2010-BR-ENC	140

External Resistor Method With Load:

When the system is run with a load, the allowable frequencies will change according to the the load inertia and rotation speed. Use the following equation to calculate the allowable frequency:

- Allowable Frequency =
  [(Allow Freq w/o Load) / (m+1)] x [(Rated Speed) / (Operating Speed)] times/min

Where:
m = load/motor inertia ratio

Electromagnetic Brake

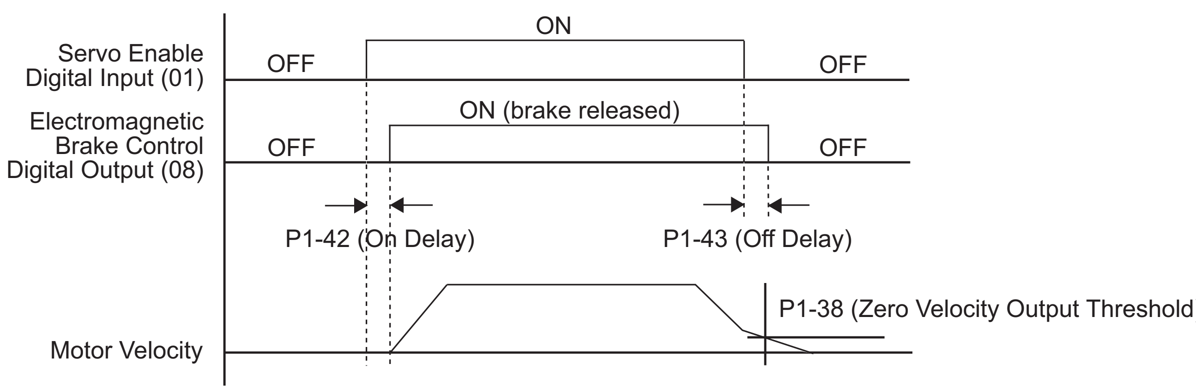
Some *Sure*Servo motors (part # SVx-xxxB) have an internal spring-loaded holding brake. These brake motors are generally used in applications where the load needs to be held up opposite the force of gravity, or needs to be held tight when power is removed from the system.

To control the brake in a brake motor, a digital output MUST be configured to control the brake (P2-18~P2-22 set to 08; Electromagnetic Brake Control), and that output should be used to activate an interposing 24 Vdc control relay with contacts rated to withstand at least 1A. Use a surge suppressor across the relay coil to protect the drive output. The servo drive VDD 24V power source can be used to power the relay coil, but do NOT use VDD to power the servo motor brake coil. For complete wiring information, refer to the electromagnetic brake diagrams in the “CN1 Input/Output Wiring Diagrams” section of the “Installation and Wiring” chapter of this manual.

There are two parameters that affect the brake operation. Parameter P1-42 is used to set the time window between when current is applied to the motor and when the brake releases. Parameter P1-43 is used to set the time window between when the brake is engaged and when the servo current is removed from the motor.

If users desire to control the electromagnetic brake by an external controller, instead of by the servo drive, users must execute the function of electromagnetic braking during the time when the servo motor is braking.

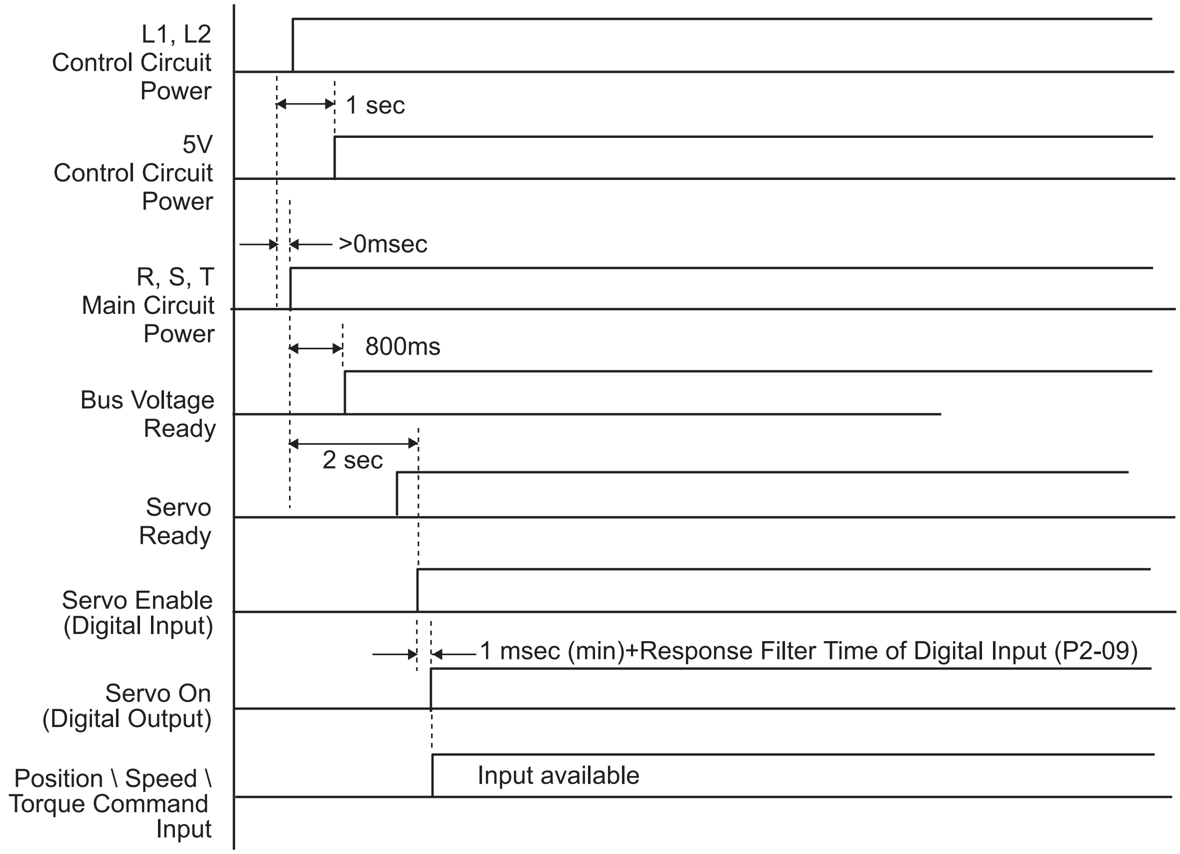
Timing chart for using servo motor with electromagnetic brake:



After the Servo Enable DI (P2-10~P2-17 set to 01) is OFF, and then the delay time set by P1-43 is reached, the EBC (Electromagnetic Brake Control) output goes OFF, even if the motor velocity is still higher than the setting value of P1-38.

After the Servo Enable DI (P2-10~P2-17 set to 01) is OFF, if the motor speed is lower than the setting value of P1-38, the EBC (Electromagnetic Brake Control) output goes OFF, even if the delay time set by P1-43 has not been reached.

Timing charts of control circuit power and main circuit power:

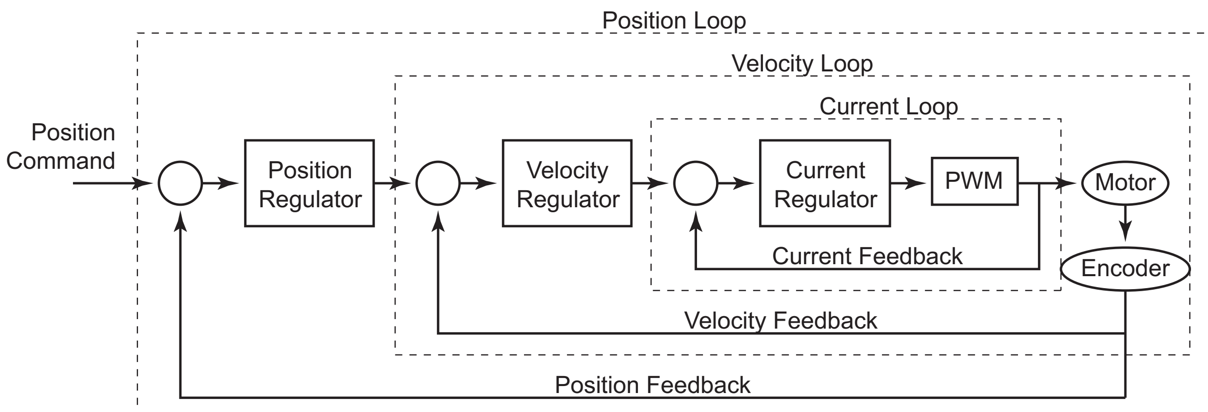


Tuning Modes Overview

Purpose of Tuning; Why and When it is Necessary

What is tuning and why is it necessary? Servo systems essentially operate by reducing the error between the command input and the output to zero. How hard it tries to make the error zero depends on how the system is tuned. Tuning is basically adjusting the servo system's reaction to any given error to achieve a desired response. Mostly in high performance servo system applications, the goals are to have a high **response rate** (also called **bandwidth**) to the error, and to keep the error as small as possible both when running and when at rest. There are, however, many applications that require a slower response, and that an amount of following error always exists while the system is moving. The key to a well tuned system is not that it closes the error margin as quickly as possible, but that it reacts to error as desired by the machine designer.

In general, before the servo system is installed on the machine, test it to make sure that the system runs smoothly when unloaded. If it is runs roughly before it is installed and loaded, there is very little chance that the desired performance will be achieved. Following are some procedures and hints on *Sure*Servo tuning methods.



The control loop diagram (above) shows the basics of how the servo drive controls the load. As shown, there are three major parts to a servo control system: current loop, velocity loop, and position loop. **Tuning is required only on position and velocity control loops.** The current loop does not require any user interaction except to select the proper motor (P1-31), and is set at a fixed **bandwidth (BW)** of 1.8kHz. If the wrong motor is selected, then the performance of the current loop will not be optimal and could ultimately cause damage to the motor. The output of the velocity loop feeds the current loop. The bandwidth of the velocity loop is adjustable up to 450Hz. The position loop output feeds the velocity loop and the bandwidth is adjustable up to 300Hz. As you can see, the current loop is the most responsive in order to process and correct the error being fed by the velocity loop. With the velocity loop at the highest BW setting, the current loop is still four times faster in order to keep the system stable. The velocity should always be more responsive than the position loop as well. Think of it this way, if the position loop updated the velocity loop faster than the velocity loop could correct the error, then the system has no choice but to become unstable.

The inner loops MUST always be faster (higher BW) than the loop that is feeding it.

*Sure*Servo™ Tuning Modes Available

*Sure*Servo™ servo systems have a choice of three types of tuning modes to suit your application; manual, auto, and easy tuning modes. Parameter P2-32 selects the tuning mode, and a general description of each one can be found below:

Manual Tuning Mode (P2-32 = 0):
This is a common tuning mode available in most servo systems. It is intended for use by experienced users who are familiar with loop gains and their effects on the system. No automatic adjustments are made by the system.

Easy-Tune Mode (P2-32 = 1):
Although this mode is not common to other name brand systems, it is available in *Sure*Servo servo systems. This mode is used when the mismatch ratio J_{Load}/J_{Motor} is higher than the preferred ratio of 10:1 or lower, or when the mismatch ratio has a wide range. Easy-Tune is used primarily to keep the system stable under a wide range of inertia mismatches, and is recommended for loads with varying inertias. The user sets the required stiffness of the system based on the mismatch ratio, and the system makes adjustments to the tuning loops accordingly.

Adaptive Auto-Tune Modes (P2-32 = 2 or 4):
These modes should be used when the load inertia is not known. These modes allow the system to determine the load inertia and continuously monitor it for changes, and should be used only when the load varies over a small range. Users adjust the level of responsiveness based on the system requirements. Mode 2 (P2-32 = 2) uses a PI (Proportional-Integral) tuning method, and Mode 4 uses a PDFF (Pseudo-Derivative Feedback and Feedforward) tuning method.

Fixed Auto-Tune Modes (P2-32 = 3 or 5):
These modes are used when the load inertia is known and the mismatch ratio can be determined. These modes use the fixed inertia information and automatically adjust tuning loops, and should be used only when the load varies over a small range. Users adjust the level of responsiveness based on the system requirements. Mode 3 (P2-32 = 3) uses a PI (Proportional-Integral) tuning method, and Mode 5 uses a PDFF (Pseudo-Derivative Feedback and Feedforward) tuning method.

Using Multiple Tuning Modes:
A common method of tuning a new machine with a rigidly coupled fixed load is use the default tuning mode (P2-32 = 4) to let the system determine the load inertia. Then the tuning mode can be changed to one of the non-adaptive modes (P2-32 = 0, 2, or 5) to further tune the system manually, if required.

Tuning Modes and Their Relevant Parameters

Tuning Modes and Their Relevant Parameters (Table 6-1)				
Tuning Mode	**P2-32**	**Parameters Set by System**	**Parameters set by User**	**Gain Values**
Manual	0	None	P2-00 Proportional Position Loop Gain (KPP) P2-06 Velocity Loop Proportional Gain (KVP) P2-25 Low-pass Filter (Resonance Suppression)	Fixed
Easy-Tune	1	P2-04 P2-06 P2-26	P2-31 Stiffness Level P2-00 Proportional Position Loop Gain (KPP) P2-25 Low-pass Filter (Resonance Suppression)	Fixed
Auto-Tune PI (Adaptive)	2	P2-00 P2-04 P2-06	P2-31 Responsive Level P2-25 Low-pass Filter (Resonance Suppression)	Continuous Adjusting
Auto-Tune PI (Fixed Inertia)	3	P2-00 P2-04 P2-06	P1-37 Inertia Mismatch Ratio P2-31 Responsive Level P2-25 Low-pass Filter (Resonance Suppression)	Fixed
Auto-Tune PDFF (Adaptive)	4	P2-00 P2-04 P2-06 P2-25 P2-26	P2-31 Responsive Level	Continuous Adjusting
Auto-Tune PDFF (Fixed Inertia)	5	P2-00 P2-04 P2-06 P2-25 P2-26	P1-37 Inertia Mismatch Ratio P2-31 Responsive Level	Fixed

Monitoring System Performance

There are tools available to assist in examining system responses while tuning: two analog monitor outputs available on I/O terminal CN1, and *Sure*Servo Pro configuration software available for download. As you change tuning parameters, you can witness the effects in real time using one of these methods. The analog monitor outputs are used by connecting an oscilloscope and capturing the waveforms for review. (The “Installation and Wiring” chapter contains information regarding terminal CN1 and these analog outputs.) Use parameters P0-03, P1-03, P1-04, and P1-05 to configure the analog monitors. Refer to the “*Sure*Servo Drive Parameters” chapter for detailed information regarding the configuration of these parameters.

For example, to observe the analog voltage command signal in channel 1 scaled to 8V per 325kpps, set the value of P1-04 (Analog Monitor Output Scaling 1 (ch1)) to 50. Another related monitor parameter is P0-03 which is used to set the monitor polarity of both channels. These monitors have 10 bit resolution (approx 15.6 mV per bit).

*Sure*Servo Pro software has a real-time scope that displays data received from the drive. This software receives data from the drive via the serial link and compiles it in a scaled output display on your PC. You can print the results to your printer or store them to disk for review later.

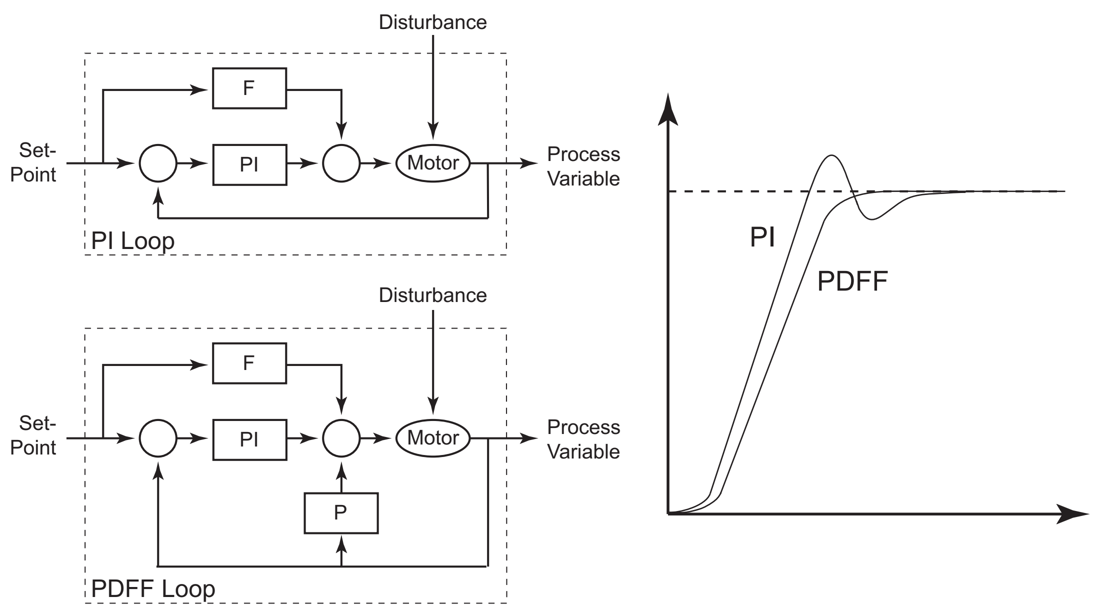
Either monitoring method is a good tool to assist with the tuning process.

Tuning Modes Details

Auto-Tuning Modes

There are two modes of auto-tuning available for use in the *Sure*Servo systems: **Adaptive** and **Fixed**. The Adaptive modes continuously monitor the load and determine the inertia mismatch ratio so the system tunes itself based on a response level set by the user. The Fixed modes tune the system based on a fixed inertia mismatch ratio and response level entered by the user. The response level is adjusted using parameter P2-31.

There are two types of tuning methods in both Adaptive modes and Fixed modes of auto-tuning: **PI** method and **PDFF** method. The differences in the control methodology are shown below:



The graph shows a relative difference between PI and PDFF step responses given the same input. In general, the PDFF control method includes additional feedback into the system to reduce following error. The PI method has a few more adjustments available to the user than does the PDFF method

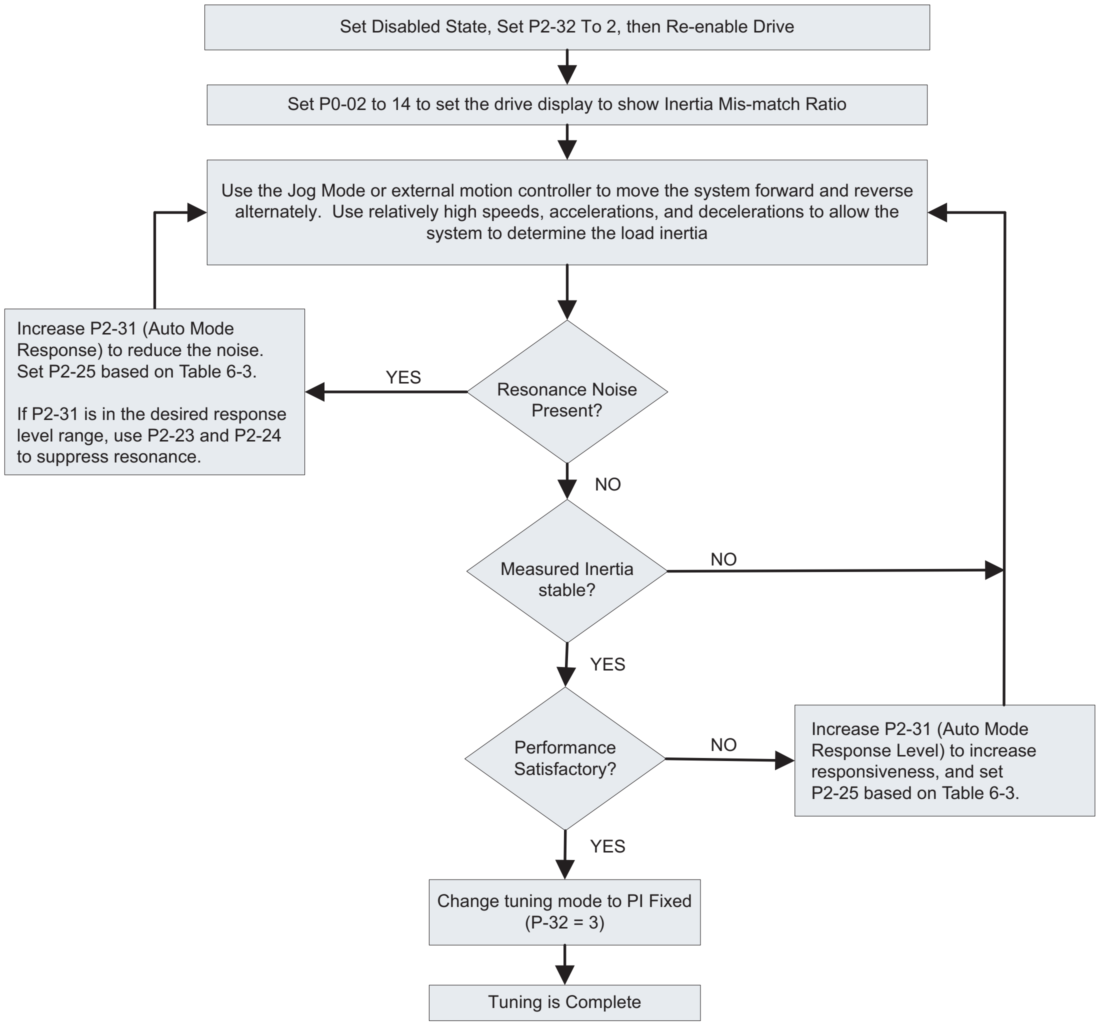
Table 6-2 shows the responsive level with respect to the settings in parameter P2-31. Essentially, the lower the setting in P2-31, the lower the bandwidth (less responsive), and the higher the setting, the higher the bandwidth (more responsive).

Velocity Loop Response Settings for Both Auto-Tune Modes (Table 6-2)		
P2-31 Auto-Tune Response	**Responsiveness in Auto-Tune PI Tuning Mode**	**Responsiveness in Auto-Tune PDFF Tuning Mode**
0	20Hz	20Hz
1	30Hz	30Hz
2	40Hz	40Hz
3	60Hz	50Hz
4	85Hz (Default setting)	60Hz (Default setting)
5	120Hz	70Hz
6	160Hz	80Hz
7	200Hz	100Hz
8	250Hz	120Hz
9	300Hz	140Hz
A	300Hz	160Hz
B	300Hz	180Hz
C	300Hz	200Hz
D	300Hz	220Hz
E	300Hz	260Hz
F	300Hz	300Hz
Note: The settings for the PI method is fixed at 300Hz for P2-31 values of 9~F(hex).		

Using Auto-Tune PI Mode

Below is a flowchart for use as a tuning guideline when using the PI Auto-Tune Mode. In general, increasing the setting of P2-31 increases the responsiveness of the system and reduces noise. Adjust P2-25 (refer to Table 6-3) along with the bandwidth setting of P2-31 to complete the response adjustment. Continuously adjust these two parameters until satisfactory performance is achieved.

Auto-Tune PI Method



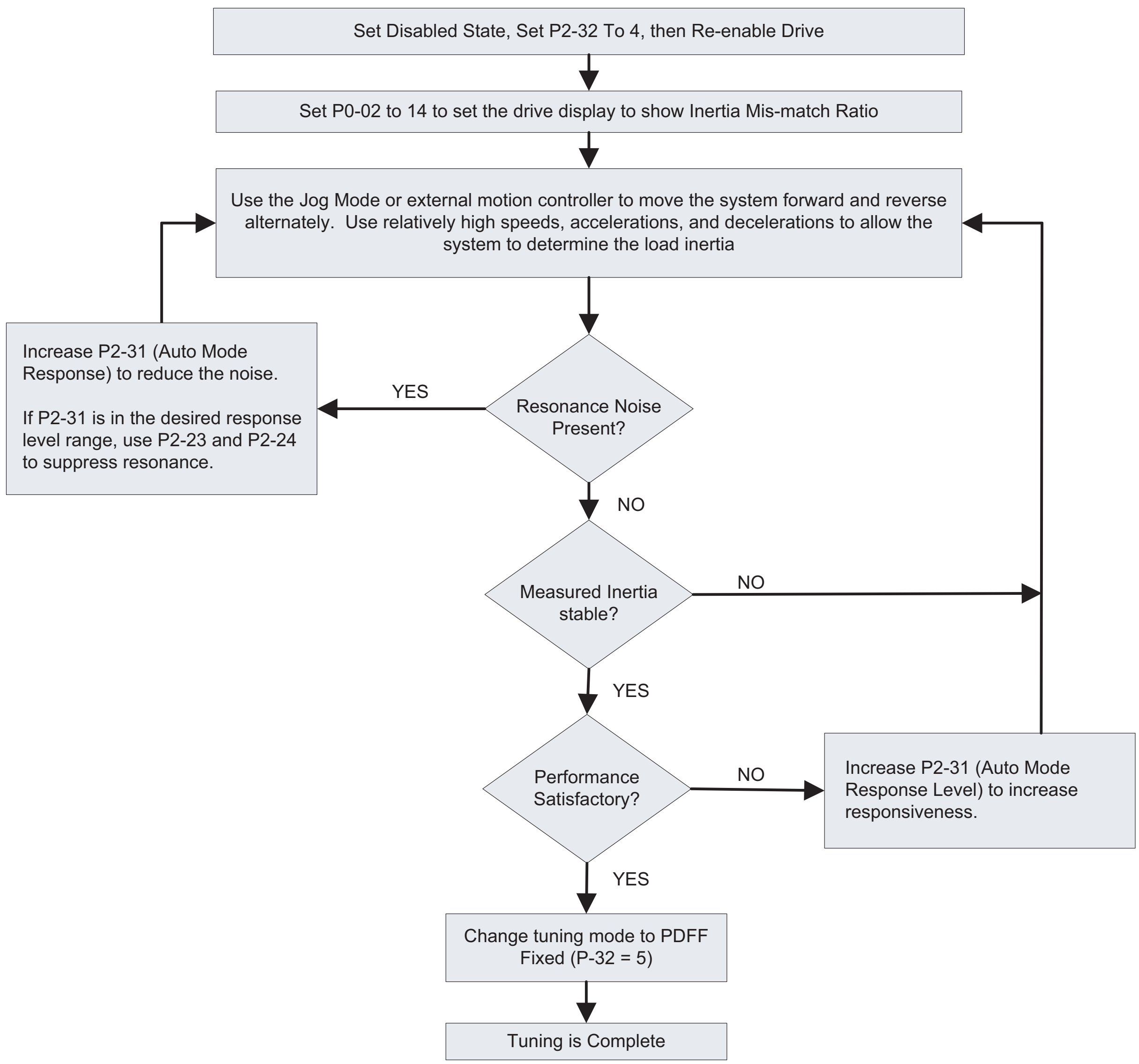
P2-25 Values with respect to Velocity Loop Gain (Auto-Tune PI Modes Only) (Table 6-3)

P2-31 Auto-Tune Response Setting	Velocity Loop Response	Recommended P2-25 Setting
0	20Hz	13
1	30Hz	9
2	40Hz	6
3	60Hz	4
4	85Hz	3
5	120Hz	3
6	160Hz	2
7	200Hz	1
8	250Hz	1
9 and above	300Hz	0

Using Auto-Tune PDFF Mode

Below is a flowchart for use as a tuning guideline when using the PDFF Auto-Tune Mode. In general, increasing the setting of P2-31 increases the responsiveness of the system and reduces noise. Adjust this parameter until satisfactory performance is achieved. Table 6-4 (previous page) shows the velocity loop responsiveness for the various setting values of P2-31.

Auto-Tune PDFF Method

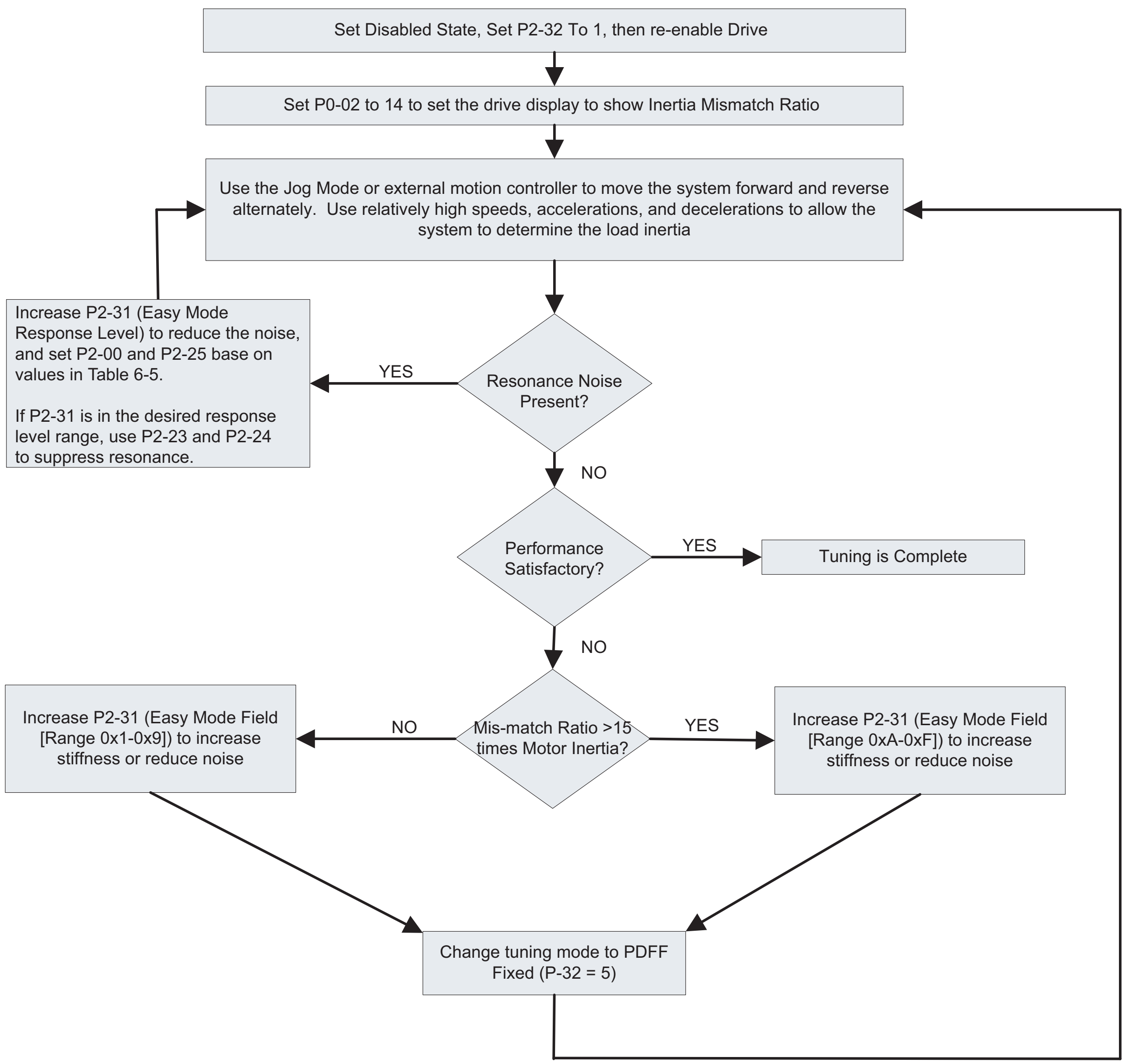


Velocity Loop Response to P2-31 (Auto-Tune PDFF Modes) (Table 6-4)			
P2-31 Auto-tune Response Setting	**Velocity Loop Responsiveness**	**P2-31 Auto-tune Response Setting**	**Velocity Loop Responsiveness**
0	20 Hz	**8**	120 Hz
1	30 Hz	**9**	140Hz
2	40 Hz	**A**	160 Hz
3	50 Hz	**B**	180 Hz
4	60 Hz	**C**	200 Hz
5	70 Hz	**D**	220 Hz
6	80 Hz	**E**	260 Hz
7	100 Hz	**F**	300 Hz

Using Easy-Tune Mode

Easy-Tune mode is used on systems that have loads that vary over a relatively wide range. The *Sure*Servo system automatically tunes the system based on a known mismatch ratio. Below is a flowchart for use as a tuning guideline when using the Easy-Tune Mode. The user can simply set the stiffness setting (P2-31 Easy-Tune Response) based on the load, enter a couple of recommended settings, and then fine tune the system based on actual system response. Table 6-5 shows the relationships between Easy-Tune Mode tuning parameters.

Easy-Tune Method



Easy-Tune Parameter Relationships (Table 6-5)					
Responsiveness Level	**Easy-Tune Response P2-31**	**Inertia Mismatch Ratio P1-37**	**Max Load Corresponding Ratio**	**Recommended P2-00 Setting**	**Recommended P2-25 Setting**
Low	1	50~100	5Hz	5	50
	2	30~50	8Hz	8	31
	3	20~30	11Hz	11	33
	4	16~20	15Hz	15	16
Medium	5	12~16	20Hz	20	12
	6	8~12	27Hz	27	9
	7	5~8	40Hz	40	6
	8	2~5	60Hz	60	4
	9	0~2	115Hz	115	2
High	A	0~2	127Hz	127	1
	B	2~8	103Hz	103	2
	C	8~15	76Hz	76	3
	D	15~25	62Hz	62	4
	E	25~50	45Hz	45	5
	F	50~100	36Hz	36	6

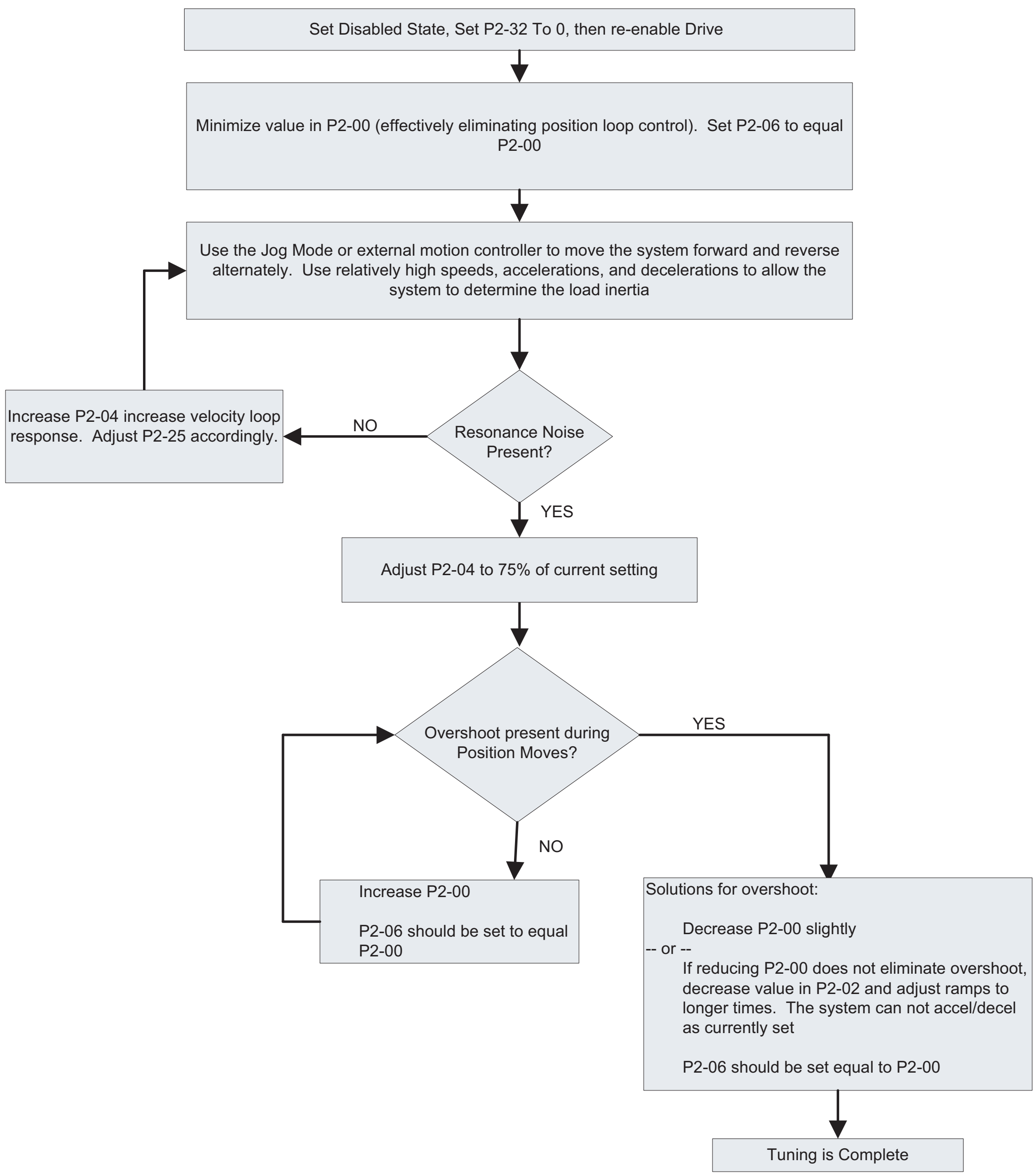
Note: The values of P2-00 and P2-25 must be entered manually.

Using Manual Tuning Mode

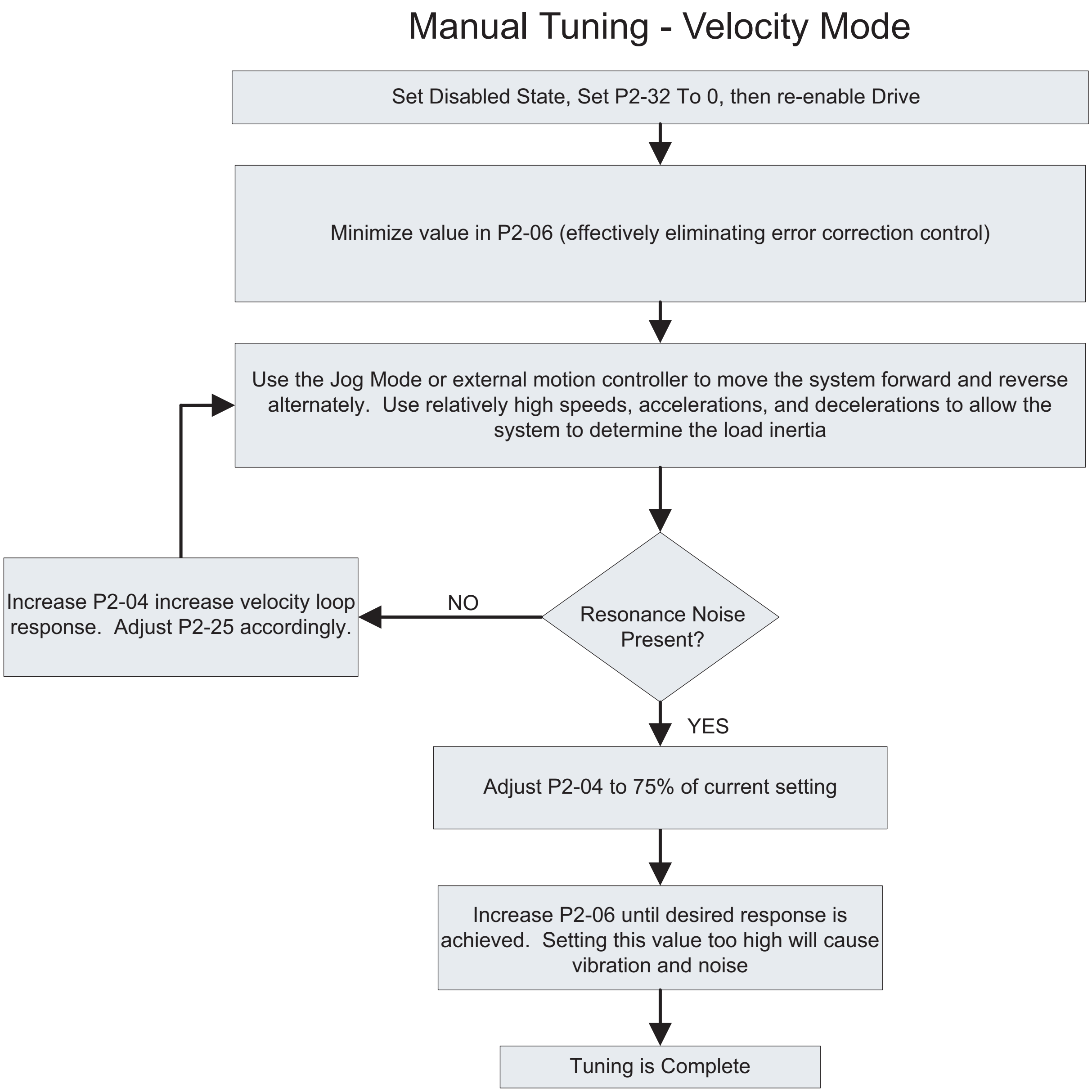
Manual tuning mode is generally used when fine tuning of the system is required. This mode should be used only by experienced users familiar with general servo system theories. The *Sure*Servo system does not automatically change any parameters in this mode. Below is a flowchart for use as a guideline when using the Manual Tuning Mode for both Position and Velocity control modes.

Manual Position Mode

Manual Tuning - Position Mode



Manual Velocity Mode



Manual Tuning Mode Details

Tuning a new system for the first time has its challenges. Sometimes it is necessary to address a difficult tuning application using the manual mode. This mode requires the user be an expert in servo system architecture and system tuning. In general the Auto-Tune and Easy-Tune modes will address a majority of the applications that *Sure*Servo systems are applied.

Gain Adjustment in Manual Tuning Mode

The position and speed responsiveness setting is depends on, and is determined by, the desired control stiffness of machinery and conditions of applications. Generally, high responsiveness is essential for the high frequency positioning control of mechanical facilities and the applications of high precision process systems. However, the higher responsiveness may easily result in the resonance of the machinery. When adjusting the responsiveness of unfamiliar loads, the user can gradually increase the gain setting value to improve responsiveness until the resonance occurs then decrease the gain setting value slightly. The relevant parameters and gain adjusting methods are described as follows:

- **P2-00: Position Loop Proportional Gain (KPP)**

This parameter is used to determine the responsiveness of position loop (position loop gain) and is used to increase stiffness and reduce position error. With higher values of KPP, the response to the position command is quicker, the position error is less, and the settling time is shorter. However, if the setting is too high, the machinery system may generate vibration or noise, or even overshoot during positioning.

Position Loop Bandwidth (Hz) = KPP ÷ 2π

- **P2-02: Position Feed Forward Gain (KFF)**

This parameter is used to reduce position error and shorten the positioning settling time. However, if the value is set too high, it may easily lead to the overshoot of the machinery system. If the value of electronic gear ratio (i.e. P1-44 / P1-45) is higher than 10, the machinery system may also easily generate vibration or noise. Determine an appropriate value for P2-02 (KFF) by trial and error.

- **P2-04: Velocity Loop Proportional Gain (KVP)**

This parameter is used to determine the responsiveness of velocity loop (velocity loop gain) and it used to set the velocity loop response (BW). With higher values of KVP, the response to the velocity command is quicker. However, if the setting is too high, it may result in unwanted mechanical resonance of the system. The velocity loop must be 4~6 times the responsiveness of position loop. If the position loop gain is nearly the same or higher than the velocity loop, the servo system may generate vibration or noise, overshoot during positioning, and become unstable.

Velocity Loop Bandwidth (Hz) = KVP ÷ [(1 + 2π) (P1-37)]

- **P2-06: Velocity Loop Integral Compensation (KVI)**

Higher setting values of KVI improve the capability of decreasing the speed control deviation. However, if the setting value is too high, it may easily result in the vibration of the machinery system.

The recommended setting value is as follows:

P2-06 ≤ (1.5) (Velocity Loop Bandwidth)

- **P2-25: Low-pass Filter (Resonance Suppression)**

Use this parameter to suppress or eliminate the noise or resonance. As the inertia mismatch ratio increases, the velocity loop bandwidth (KVP) may be increased to maintain the responsiveness of system. However, increasing KVP may easily result in the vibration of the machinery system. Increasing P2-25 should reduce the noise or resonance. Setting P2-25 too high will lead to the instability of the velocity loop and overshoot of the machinery system.

The recommended setting value is as follows:

P2-25 ≤ 1000 ÷ [(4) (Velocity Loop Bandwidth)]

- **P2-26: External Anti-Interference Gain (used in PDFF modes)**

This parameter is used to enhance the anti-interference capability and reduce the occurrence of overshoot. The default setting is 0 (Disabled). It is not recommended to be used in Manual Mode unless its value is determined by the adaptive fixed Auto-Tune PDFF mode (P2-32 = 5). Once the value is determined in mode 5, it can be left when the tuning mode is set to Manual (P2-32 = 0).