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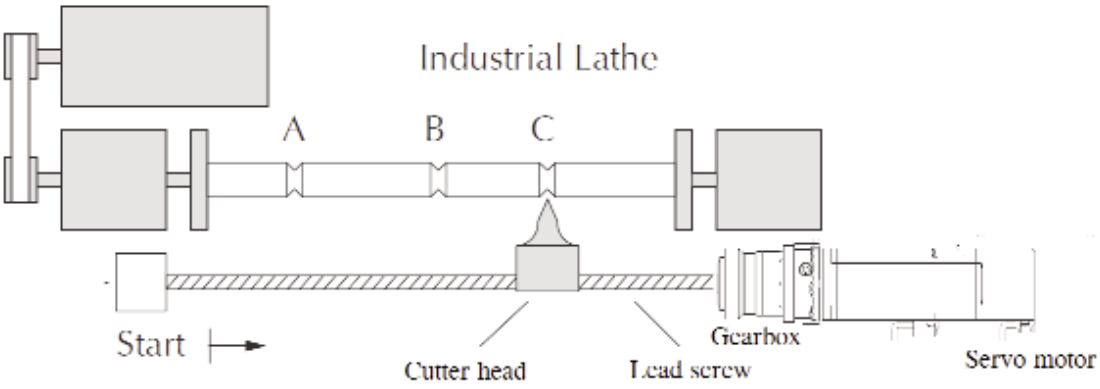
PRODUCT FAMILY: Sure Servo
Number: AN-SERV-001
Subject: Sureservo position with internal registers (Pr)
Date issued: April-13-2006
Revision: Rev D, March-2017

We will control the motion of the tool in an industrial lathe to execute 3 grooves by means of programmable position targets on the Sureservo drive .

In this simple example, we will determine the kinematics and dynamics of the movement, the sizing of the servo motor and discuss some design considerations; then we will wire the servo drive to the PLC DL06. We will show the wiring of the drive, the program of the PLC and the programming of the servo drive, including the actions to tune the servo.

ADC does not support sizing but this subject is detailed to show the concepts.

See the following diagram to explain the concept.



The rod installed on the spindle of the lathe will receive 3 grooves that, for this example will be located on positions A, B and C.

The lead screw that displaces the tool is 108 inches long and one of the sides is coupled to the servo motor, thru a gear-reducer. The operation is the following:

At the start of the job, the Start button on the PLC will position the tool holder at Home, if not in Home position. After that, the servo will move the tool holder to position A. The spindle will rotate; then the tool will advance while the chuck (or spindle) rotates until the groove is done; The spindle will continue to rotate; the tool will return to retracted position. Position sensors will detect the displacement of the tool holder and will maintain the servo stopped. The servo's brake is applied during this time. Using the same procedure, the tool holder will repeat the sequence at position B and Position C. At the end of the cycle, the tool holder will return to the home position, to wait for next cycle. The spindle will stop rotating.

The positions A, B and C are, for this example, respectively 4.5″, 54.0″ and 100.0″ from the home position.

There is a proximity sensor or limit switch to indicate the Home position to the drive.

Kinematics calculations

Here we will determine the relationship between the physical motion tool holder on the lathe and the revolutions of the motor.

The technical data for the lead screw are:

Weight of the tool holder	25 lb	11.35 kg
Friction coeficient	0.15	
External load force	0	
Lead screw shaft diameter	1 inch	25.4 mm or 0.0254 m
Lead screw length (stroke)	108 inches	2.7432 m
Lead screw material	steel	
Pitch	5 rev/inch	196.85 rev/m
Efficiency	0.9	
Gear reducer ratio	to be decided after calculations below.	

The pitch of the lead screw is 5 revolutions per inch (or a lead of 0.2 inch/revolution).

The lead screw cannot run more the 500 rpm, per manufacturer limitations.

Since a revolution corresponds to 0.2 inches , then the:

- first preset absolute position is 4.5[inch] * 5[revolutions/inch] = 22.5, equivalent to 22 revolutions + 5000 counts
- preset absolute position is 54[inch] * 5[revolutions/inch] = 270.0, equivalent to 270 revolutions + 0 counts
- third preset position is 100[inch] * 5[revolutions/inch] = 500, equivalent to 500 revolutions + 0 counts

Since we have an acceleration of 1 second and the deceleration of 1 second, and the lead screw speed should be as maximum 500 rpm (limitation by manufacturer) or 8.333 rev/second, the total time on the first displacement will be:

a)**Move to position A**: In the first second, we will reach 8.3333 rev/second; then the shaft rotation in this period are 8.3333 / 2 = 4.1666 revolutions; the same is true for the deceleration; the total revolutions on the constant speed for this displacement should be 22.5 - 2 * 4.1666 = 14.1668 revolutions;

Then the time of constant speed is 141.668 / 8.3333 = 1.7 seconds.

The total time for this displacement is then 1 + 1.7 + 1 = 3.7 seconds

b) **Move to position B**: In the first second, we will reach 8.3333 rev/second; then the shaft rotation in this period are 8.3333 / 2 = 4.1666 revolutions; the same is true for the deceleration; the total revolutions on the constant speed for this displacement should be 270 - 22.5 - 2 * 4.1666 = 239.1674 revolutions;

The time of constant speed is 239.1674 / 8.3333 = 28.7 seconds.

The total time for this displacement is then 1 + 18.7 + 1 = 30.7 seconds

c) **Move to position C**: In the first second, we will reach 8.3333 rev/second; then the shaft rotation in this period are 8.3333 / 2 = 4.1666 revolutions; the same is true for the deceleration; the total revolutions on the constant speed for this displacement should be 500 - 270 - 22.5 - 2 * 4.1666 = 199.4668 revolutions;

The time of constant speed is 199.4668 / 8.3333 = 23.93 seconds.

The total time for this displacement is then 1 + 23.93 + 1 = 25.93 seconds

These considerations allows us to do the calculations to define the size of the servomotor.

Let us consider that the servo will run at 3000 rpm; in this case the gear ratio should be 3000/500 = 6:1; looking in the **Automation Direct** catalog, the closest planetary gearhead we could find is a gearbox with 5:1 ratio or a 10:1 ratio. In one case the servo motor shall run at 2500 rpm. In the other case at 5000 rpm.

When the size of the servomotor is determined, we can then select the proper drive and design the control from the PLC.

Dynamics calculations:

In order to size the motor we have to determine the torque demanded by the machine along the motion cycle.

The required torque at any given time is the running torque due to the loads in the mechanical parts and the dynamic torque due to acceleration and deceleration of the masses involved.

The running torque can be determined using the formulas in the Sureservo user manual:

$\mathbf{T_{run} = ((F_{total} / (2 * \pi * P)) + T_{preload}}$ being **P** the pitch of the lead screw.

Forces acting on the lead screw:

Friction: 0.15 * 11.35 [Kg] * 9.81 [Newton] = 16.7 [N] on the load side

Preload 0.55[N-m] estimated

External forces: none

Pitch = 196.85 rev/m.

we get:

T_{run}=(16.7[N] / (2 * π * 196.85)) + 0.55 [N] = 0.5635 [N-m] in the load side.

The dynamic torque during accel is given by the formula:

Tdyn = $J_{at\ motor}$ x rpm servo * 2*π / 60 /accel time in seconds

We need the moment of inertia values of all the components, including the motor and gearbox. For the case of a gearbox of ratio 5:1:

Inertias referred to the lead screw side:

Inertia of tool holder = 11.35[Kg] * 9.81 * 0.9 / (2 * π *196.85)^2 **= 0.0000655** [Kg-m^2]

using the formula J_W = W * g * e / (2* π * Pitch)

Lead screw inertia = $\pi * 2.7432$[m] * 7700[kg/m^3] * $(0.0254/2)^4$ **= 0.0017262** [Kg-m^2] using the formula of the inertia for a cylinder

Inertia of the coupling (Let us make 0.0001 as estimate) **= 0.000100** [Kg-m^2]

Total inertia on the load side = 0.0018917 [Kg-m^2]

Let us estimate the gearbox inertia as **0.001**[Kg-m^2] referred to the motor side.

Let us estimate the inertia of the motor as **0.0005** [Kg-m^2]

The inertia referred to the side of the motor when using a gearbox of ratio 5: 1 will be :

$J_{at\ motor}$ = 0.0018917 [Kg-m^2] / 5^2+ 0.001 + 0.0005 = 0.0157668 [Kg-m^2]

using the formula **Tdyn**= $J_{at\ motor} *$ rpm servo * 2 * π / 60 / accel time in seconds

Tdyn = 0.0157[kg-m2] * 2500 rpm * 2 * π / 60[rad/s] = 4.11 [N-m] when the acceleration time is 1 second.

Notice that this calculation do not consider the gearbox efficiency.

Note also that the dynamic torque is inversely proportional to the acceleration time. This is an important consideration when the torque can be limited (or extended, as this case).

During acceleration, the required torque would be 4.11 [N-m] plus 0.5635 [N-m], from page 3. Note that the dynamic torque is added to the running torque.

During deceleration, the servo has to apply a reverse (or negative) torque to allow stopping at the proper point.

The servo motor SVL-207B would satisfy the needs; the motor maximum torque is 7.16 [N-m], per tables of the servo motor.

This motor can deliver continuously 3.3 [N-m]. The inertia of this motor is 0.000956 [Kg-m^2], smaller than the estimated value.

Let us determine now the gear reducer part # and the inertia values:

PGA070-05A3 is the recomended in line gearbox from Automation Direct. The efficiency of the gearbox is 95% and the moment of inertia referred to the input side is a 0.160 [Kg-cm^2]. This is equivalent to 0.00016 [Kg-m^2], smaller than the estimated value.

The calculation has to be repeated with the new values, Here they are:

The gearbox inertia is **0.00016** [Kg-m^2] referred to the motor side.

The inertia of the servo motor is **0.000956** [Kg-m^2]

Then the total inertia referred to the side of the motor will be :

$J_{at\ motor}$ = 0.0018917/5^2 + 0.00016 + 0.000956 = 0.0011917 [Kg-m^2]

Tdyn = 0.011917[kg-m2] * 2500 rpm * 2 * π / 60 [rad/s] = 3.12[N-m] when the acceleration time is 1 second.

During acceleration, the required torque would be 3.12[N-m] plus the running torque, from page 3. However, we have to add the efficiency of the gear box.

Running torque = 0.5635 [N-m] / 0.95 = 0.593 [N-m]

Peak torque during acceleration: 0.593 [N-m] + 3.12[N-m] = 3.71 [N-m]

The servo motor SVL-204B will satisfy the needs; the motor maximum torque is 3.82 [N-m], per tables of the servo motor.

This motor can deliver continuously 1.27 [N-m], above the required running torque.

In this case the recomended AutomationDirect gear reducer is the same as the one for the motor SVL-207B.

Let us determine now the values with a gear box of ratio 10:1:

The inertia referred to the side of the motor when using a gearbox of ratio 10: 1 will be (using the inertia values of the the selected servo motor and gearbox) :

$J_{at\ motor} = 0.0018917 / 10^2 + 0.00014 + 0.00026 = 0.000418917$ [Kg-m^2]

using the formula **Tdyn** = $\mathbf{J}_{at\ motor}$ * rpm servo * 2 * π / 60 / accel time in seconds

Then:

Tdyn = **0.000418917**[kg-m2] * 5000rpm * 2 * π / 60[rad/s] = 0.21934 [N-m] when the acceleration time is 1 second, a significant decrease in this torque portion.

During acceleration, the required torque would be 0.21934[N-m] plus the running torque determined above, about 0.593 [N-m}.

Peak torque during acceleration: 0.593 [N-m] + 1.034[N-m] = 0.8123 [N-m]

The servo motor SVL-202B would satisfy the needs; the motor maximum torque is 1.91 [N-m], per tables of the servo motor.

This motor can deliver continuously 1.27 [N-m], above the required running torque.

In this case the recomended AutomationDirect gear reducer is the PGA-070-10A2. The efficiency of the gearbox is 95% and the moment of inertia referred to the input side is a 0.140 [Kg-cm^2].

The option is clear here. Using the smaller motor of 200 Watt is better for the point of view of space, cost and energy savings.

The ratio of load inertia to motor rotor inertia is about :

0.000418917 / 0.00014 = 2.99 a very goood value for inertia matching

The next step will be to define the PLC control..

The operator of the lathe will have only 3 pushbuttons to give the commands to start and stop the cycle and the other to return to Home, in case there is a power shutdown during the operation.

Wiring between PLC and servo drive

On the DL06 PLC we will select the following functions and the corresponding output:

X0 is the start command to initiate the movement.

X1 is the command to search for home.

X2 is STOP command;

X3 is the input **Tool in retracted position**;

X22 is the **Home completed** and

X23 is **At position** and.

Y2 will be associated to the command **Trigger to Start.**

Y3and Y4 will have the signals to define the target position, as shown on the table below:

Position	POS0 Bit (Y3)	POS1 Bit (Y4)
0 rev	OFF	OFF
Target A	OFF	ON
Target B	ON	OFF
Target C	ON	ON

Y5 is the output related to the servomotor **brake** and

Y6 output is the command **run the lathe spindle**. This circuit is not shown in detail in the wiring diagram of next page.

Y7 is the command for **Tool start** (To begin to work the groove). This circuit is not shown in detailin the wiring diagram of next page.

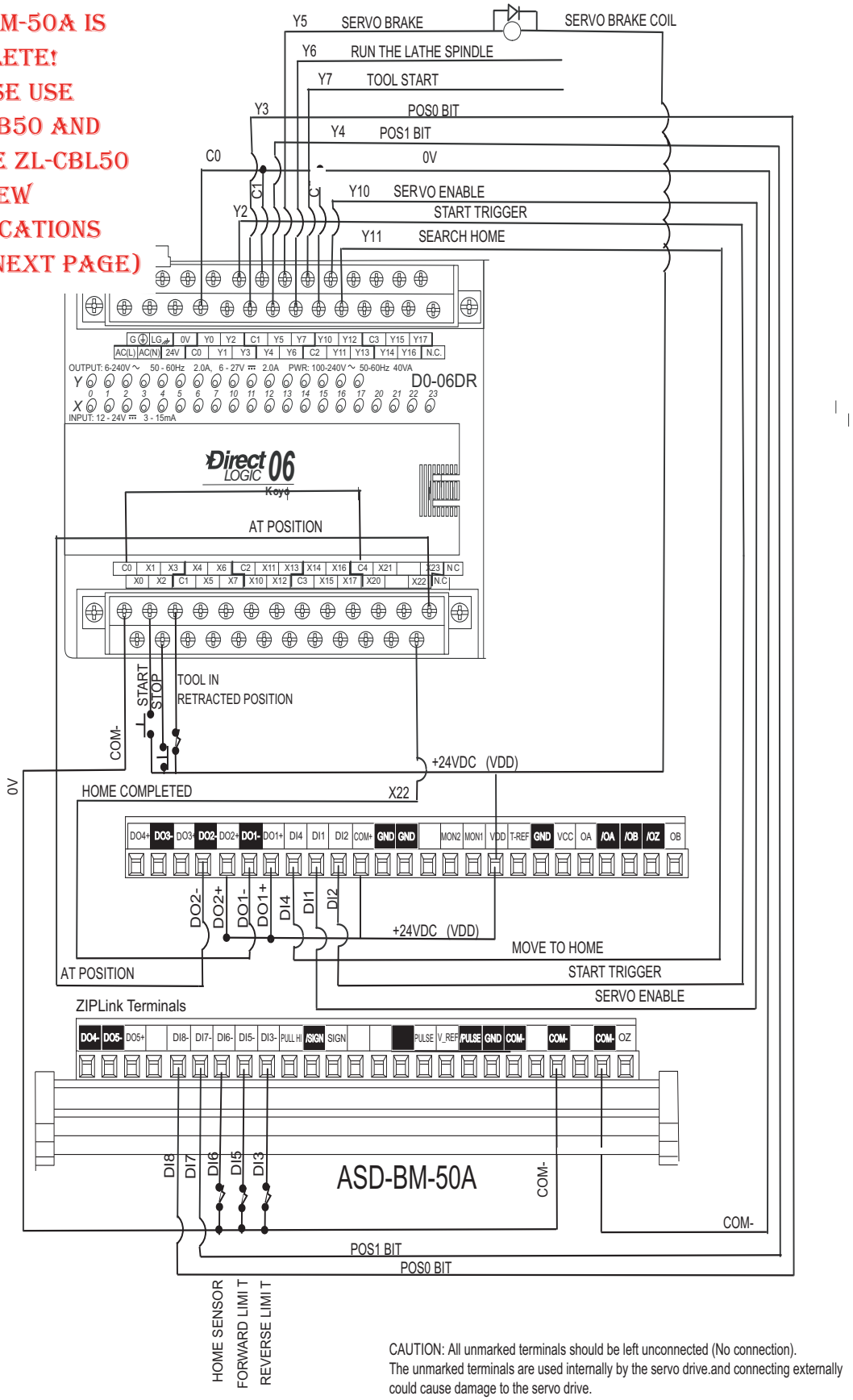
Y10 will have the command **Servo Enable.**

Y11 will have the signal to command the servo for **Search Home.**

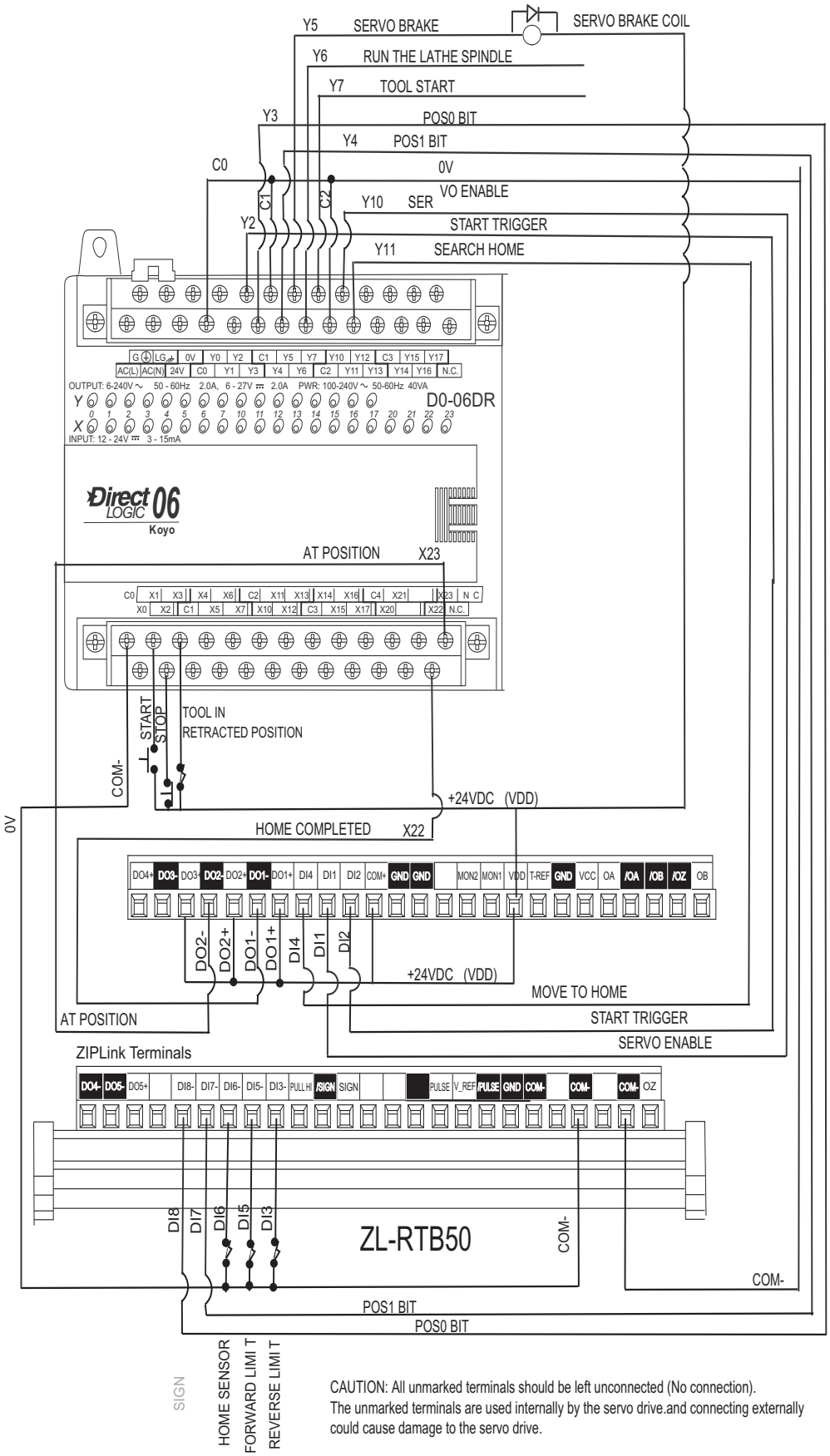
The **FWD overtravel and** the **REVERSE overtravel** limit switches are wired directly to the servo drive, as well as the **home sensor**.

The diagrams of next pages show the control connections necessary to make the system work as required.

ASD-BM-50A IS OBSOLETE! PLEASE USE ZL-RTB50 AND CABLE ZL-CBL50 FOR NEW APPLICATIONS (SEE NEXT PAGE)

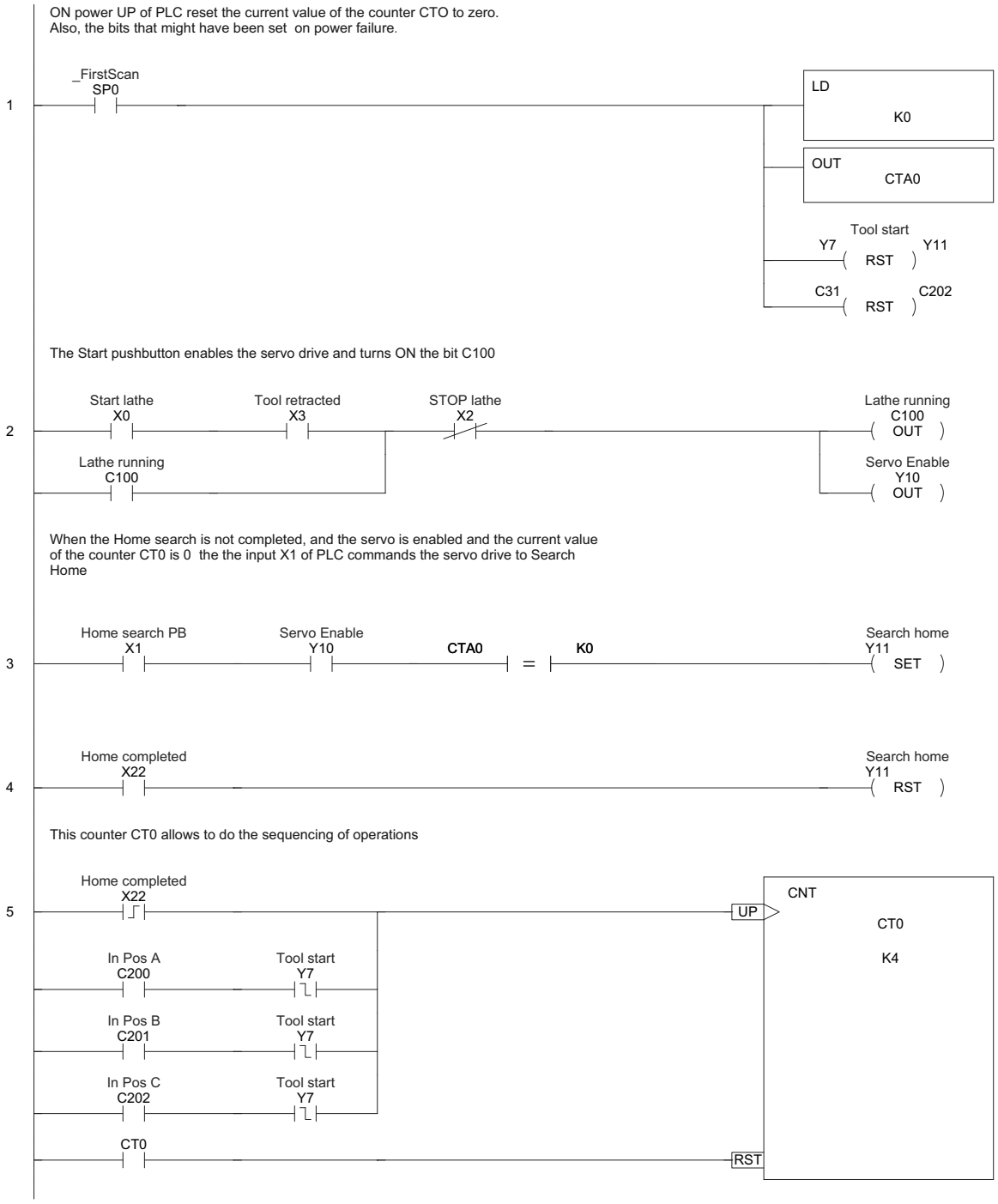


CAUTION: All unmarked terminals should be left unconnected (No connection). The unmarked terminals are used internally by the servo drive.and connecting externally could cause damage to the servo drive.



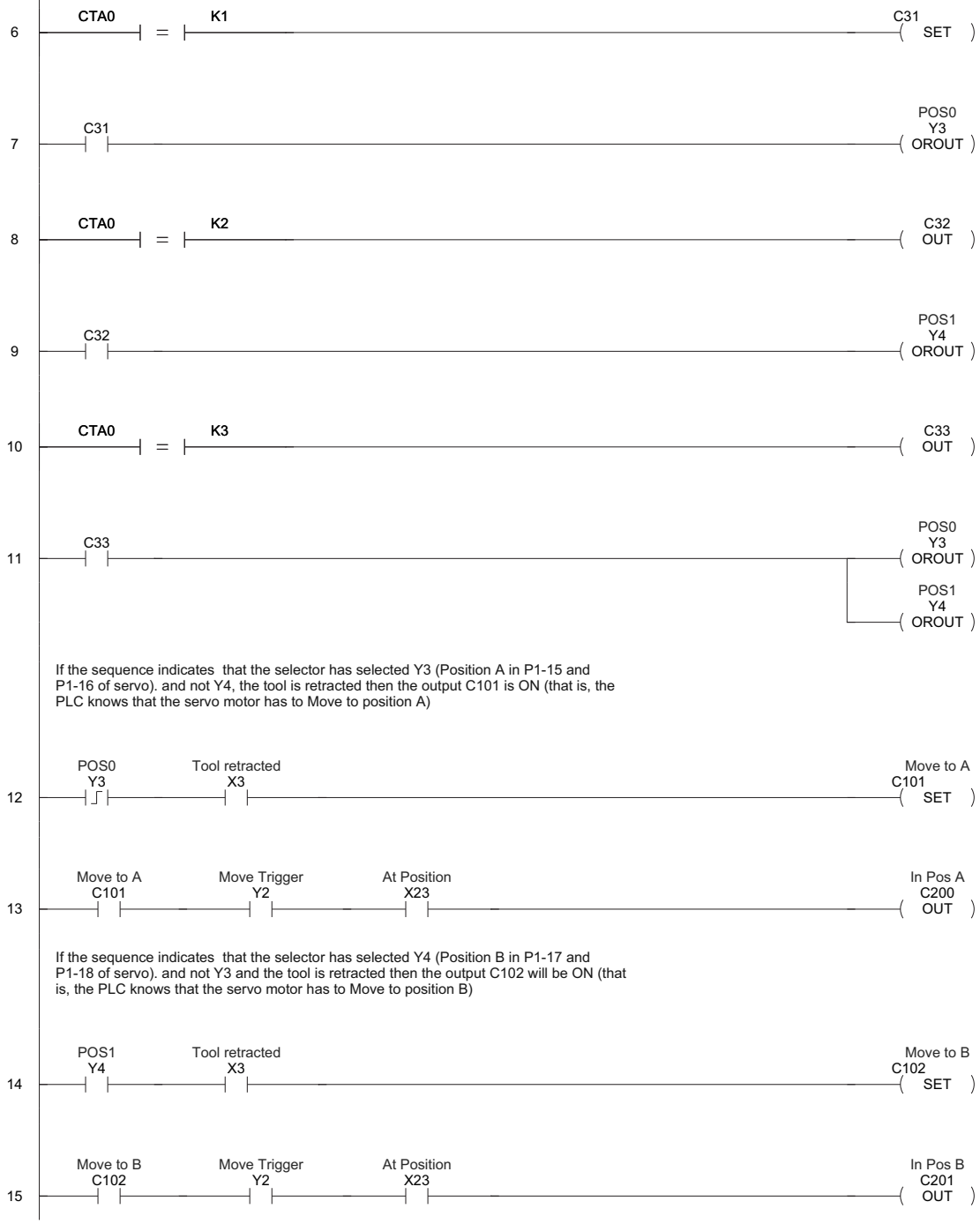
CAUTION: All unmarked terminals should be left unconnected (No connection).
The unmarked terminals are used internally by the servo drive.and connecting externally could cause damage to the servo drive.

The program of the PLC is shown below: explanations are given on the comments of the ladder diagram.



6/6/2015 AN-SERV-001-B ladder 06 an-serv-001b

- If the current value of CT0 is 0, the outputs Y3 and Y3 are OFF.
- If the current value of CT0 is 1, the output Y3 is ON and Y3 is OFF.
- If the current value of CT0 is 2, the outputs Y4 is ON and Y3 is OFF.
- If the current value of CT0 is 3, the outputs Y4 is ON and Y3 is ON.
- If the current value of CT0 is 4, the current value of the counter resets to zero.



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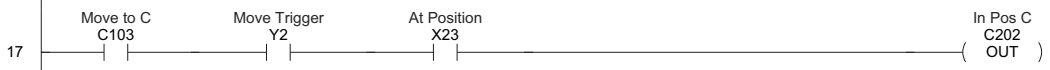
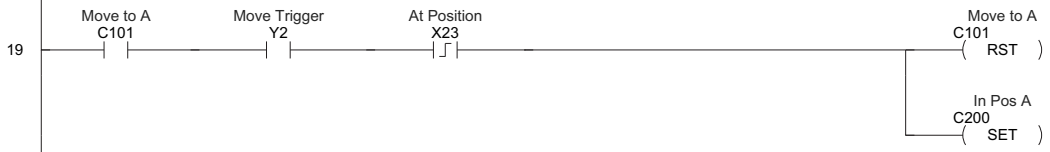
If the sequence indicates that the selector has selected Y3 and Y 4 (Position C in P1-19 and P1-20 of servo), the tool is retracted then the output C103 is ON (that is, the PLC knows that the servo motor has to Move to position C)

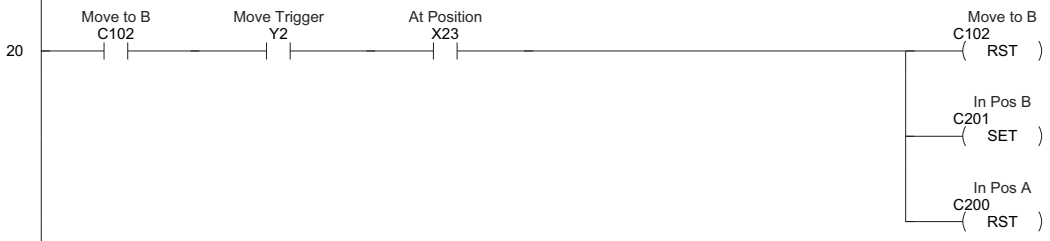


This rung turns ON the trigger command to activate the motion

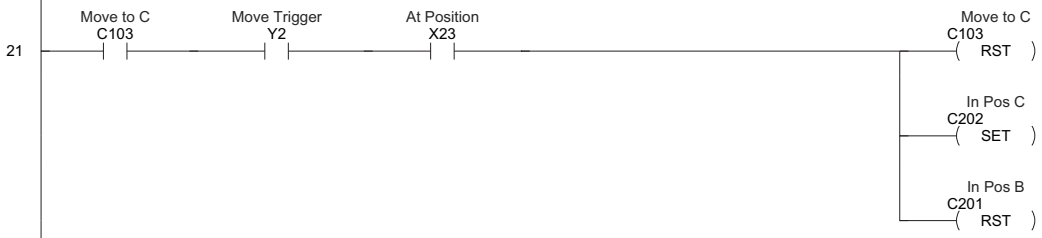
When C101 is ON, the trigger have been turned ON and the servo has stopped At Position in the leading edge the bit C200 turns ON now to indicate In Position A; bit C101 is reset because it is already in Position A.



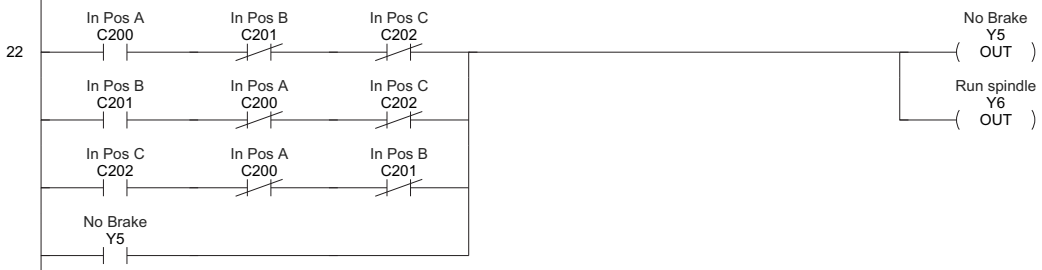
When C102 is ON, the trigger have been turned ON and the servo has stopped At Position in the leading edge the bit C201 turns ON now to indicate In Position B; bit C102 is reset because it is already in Position B. C200 is also reset to indicate that i tis not in position A anymore



When C103 is ON, the trigger have been turned ON and the servo has stopped At Position in the leading edge the bit C202 turns ON now to indicate In Position C; bit C103 is reset because it is already in Position C. C201 is also reset to indicate that it is not in position B anymore

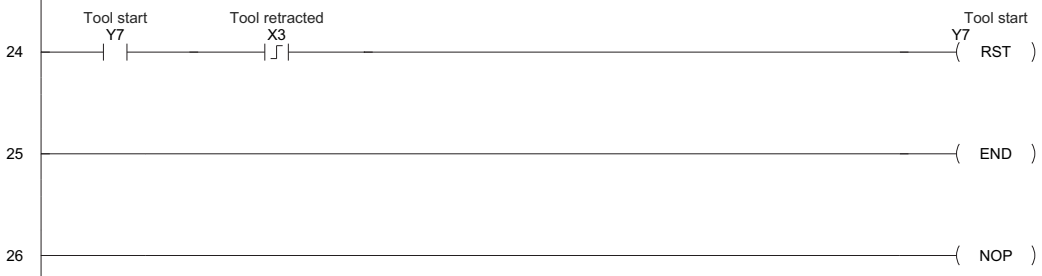


This rung releases the servo motor brake and turn on the permissive bit Y6 to run the spindle of the lathe



When the tool holder is in one of the postions (A, B or C), and the servo motor brake is released, Y7 (Tool start) is ON to move the tool to make the groove. It will run until itis reset in the next rung

The tool wil take some time to make the groove and then will be retracted. When the input X3 leading Edge is detected, this mesansd the toll is rreaxcted and then turn OFF the bit Y7



Parameter settings for the drive

P 1.01 **[3] Control mode and output direction** Setting: 0101

Range: 0 to 1110
We are selecting here Pr mode with CW direction and digital I/0, set to retain previous settings on power off.

P 1.02 **[2] Velocity limit** Default Setting: 0001

Range: 0 to 11
We are selecting here to disable the velocity and torque limits.

P 1.15 **Preset Position 1 (Revolutions)** Setting: 0

Range: +/- 30000
We are selecting here the initial position, with Y4 and &Y5 OFF.

P 1.16 **Preset Position 1 (Pulses)** Setting: 0

Range: +/- 30000
We are selecting here the initial position, with Y4 and &Y5 OFF.

P 1.17 **Preset Position 2 (Revolutions)** Setting: 22

Range: +/- 30000
We are selecting here the second target position (A). POS0 bit (Y5) is ON.

P 1.18 **Preset Position 2 (Pulses)** Setting: 5000

Range: +/- 30000
We are selecting here the second target position (A).POS0 bit (Y5) is ON.

P 1.19 **Preset Position 3 (Revolutions)** Setting: 270

Range: +/- 30000
We are selecting here the third.target position (B). POS1 bit (Y4) is ON.

P 1.20 **Preset Position 3 (Pulses)** Setting: 0

Range: +/- 30000
We are selecting here the third target position (B). POS1 bit (Y4) is ON.

P 1.21 **Preset Position 4 (Revolutions)** Setting: 500

Range: +/- 30000
We are selecting here the position C. POS0 bit (Y5)and POS1 bit (Y4) are ON.

P 1.22 **Preset Position 4 (Pulses)** Setting: 0

Range: +/- 30000
We are selecting here the position C. POS0 bit (Y5)and POS1 bit (Y4) are ON.

P 1.31 **[5] Motor code** Setting: 11

Range: 10, 11, 12, 20, 21, 22, 30, 31
We are selecting here the motor SVA-202B, 200 W

P 1.32 **Motor stop mode selection** Setting: 0

Range: 00, 01, 10, 11
We are defining here to stop with dynamic braking.

P 1.33 **[3] Position Control Mode** Setting: 0

Range: 0 - 6
We are selecting here Absolute position,

P 1.34 **Acceleration time** Setting: 1000

Range: +/- 20.000
We are selecting here 1 second acceleration.

P 1.35 **Deceleration time** Setting: 1000

Range: +/- 20.000
We are selecting here 1 second deceleration.

P 1.36 **Accel/decel S- Curve** Setting: 20

Range: +/- 10.000
We are tentatively defining the S-curve; this can be changed after real testing.

P 1.37 **Inertia mismatch ratio** Setting: 3.00

Range: 0 - 200.0
We are defining a value of 3.00, per the calculations done earlier.

.P 1.47 Homing mode **Setting: 1223**

Range: 0 - 1,225

We are defining here to move the tool holder to the sensor used to detect the Home position, start to move reverse and after detecting home position, the motor will return to home position in forward direction.

P 1.48 Homing velocity 1- Fast search Setting: 2000

Range: 1 - 2,000
We are defining the fast speed to return to Home.

P 1.49 Homing velocity 2- Creep velocity Setting: 24

Range: 1 - 50 rpm
We are defining the approximation speed to return to Home. This is really low speed and typically this will be faster. This is just to see that the creep velocity is working

P 1.50 Home position offset (Revolutions) Setting: 5

Range: +/- 10,000
We are defining here to move one inch from Home since the pitch is 5 rev/inch.

P 1.51 Home position offset (Pulses) Setting: 0

Range: +/- 10,000
We are not using any pulses in the offset

P 1.52 Regenerative resistor value Setting: 40

Range: 10 - 750 Ohms
We are selecting here 40 Ohms. This is done automatically if no external resistor is added.

P 1.53 Regenerative resistor capacity Setting: 60

Range: 30 - 1000
We are selecting here 60 Watt. This is done automatically if no external resistor is added.

P 1.55 Maximum velocity limit) Setting: 5000

Range: 0 5,000
We are defining here the velocity limit. This defines the slope of the acceleration.

P 2.10 **Digital input Terminal 1 (DI1)** Setting: 001

Range: 0 - 145
We are selecting here the **Servo Enable** signal, that is, a normally closed contact, to allow for the servo execute commands, connected to the output Y10 of PLC

P 2.11 **Digital input Terminal 2 (DI2)** Setting: 108

Range: 0 - 145
We defined **Start trigger** in this input, a normally open contact to allow execution of the move, connected to the output Y2 of PLC.

P 2.12 **Digital input Terminal 3 (DI3)** Setting: 022

Range: 0 - 145
We are selecting here the **Reverse overtravel** signal, that is, a normally closed contact to indicate the reverse overtravel, typically hardwired to the drive.

P 2.13 **Digital input Terminal 4 (DI4)** Setting: 127

Range: 0 - 145
We select here the **Move to Home** trigger signal, that is, a normally open contact to command the servo to move Home, connected to the output Y0 of PLC

P 2.14 **Digital input Terminal 5 (DI5)** Setting: 023

Range: 0 - 145
We are selecting here the **FORWARD overtravel** signal, that is, a normally closed contact to indicate the forward overtravel, typically hardwired to the drive.

P 2.15 **Digital input Terminal 6 (DI6)** Setting: 124

Range: 0 - 145
We are selecting here the **Home sensor**, that is, a normally open contact of a proximity sensor to define the Home position.

P 2.16 **Digital input Terminal 7 (DI7)** Setting: 112

Range: 0 - 145
We are selecting here the **Preset position POS1 bit Selection**, that is, a normally open contact to define the target position, with the output Y5.

P 2.17 **Digital input Terminal 8 (DI8)** Setting: 111

Range: 0 - 145
We are selecting here the **Preset position POS0 bit Selection**, that is, a normally open contact to define the target position.contact, with the output Y4.

P 2.18 **Digital output Terminal 1 (DO1)** Setting: 109

Range: 0 - 109
We are selecting the output signal **Home completed,** connected to PLC input X22.

P 2.19 **Digital output Terminal 2 (DO2)** Setting: 05

Range: 0 - 109
We are selecting here the output signal **At Position**, connected to PLC input X23.

P 2.36 **Position 1 velocity** Setting: 5000

Range: 1 - 5,000
We define here the preset velocity to move to the preset position 1 command.

P 2.37 **Position 2 velocity** Setting: 5000

Range: 1 - 5,000
We define here the preset velocity to move to the preset position 2.

P 2.38 **Position 3 velocity** Setting: 5000

Range: 1 - 5,000
We define here the preset velocity to move to the preset position 3.

Final actions

When the parameter setting is completed, it is necessary to remove the control power of the servo drive for a couple of seconds, to allow the saving of the parameters into the drive.

In order to check that the drive has the proper settings on all the parameters, we recommend to print the parameters with the help of the *Sure*servo Pro software.

Usually it is not necessary to do any tuning, if the motor is properly sized.

Create a new configuration, give it a name, reset the parameters to default by setting "10" on parameter P2-08, and use the parameters defined earlier.

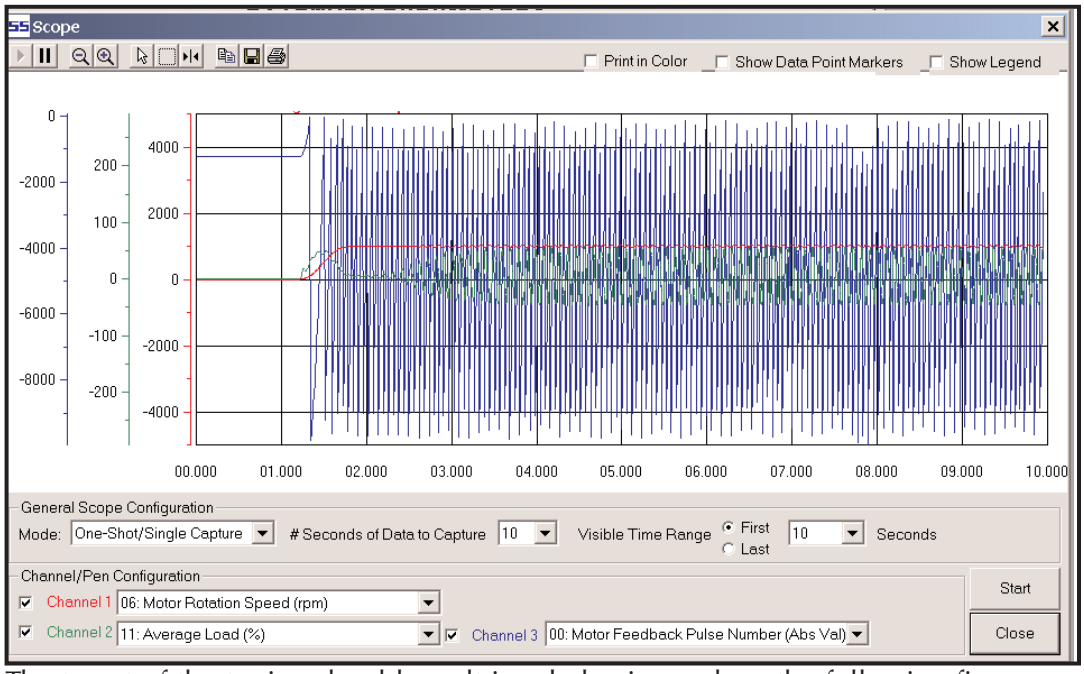
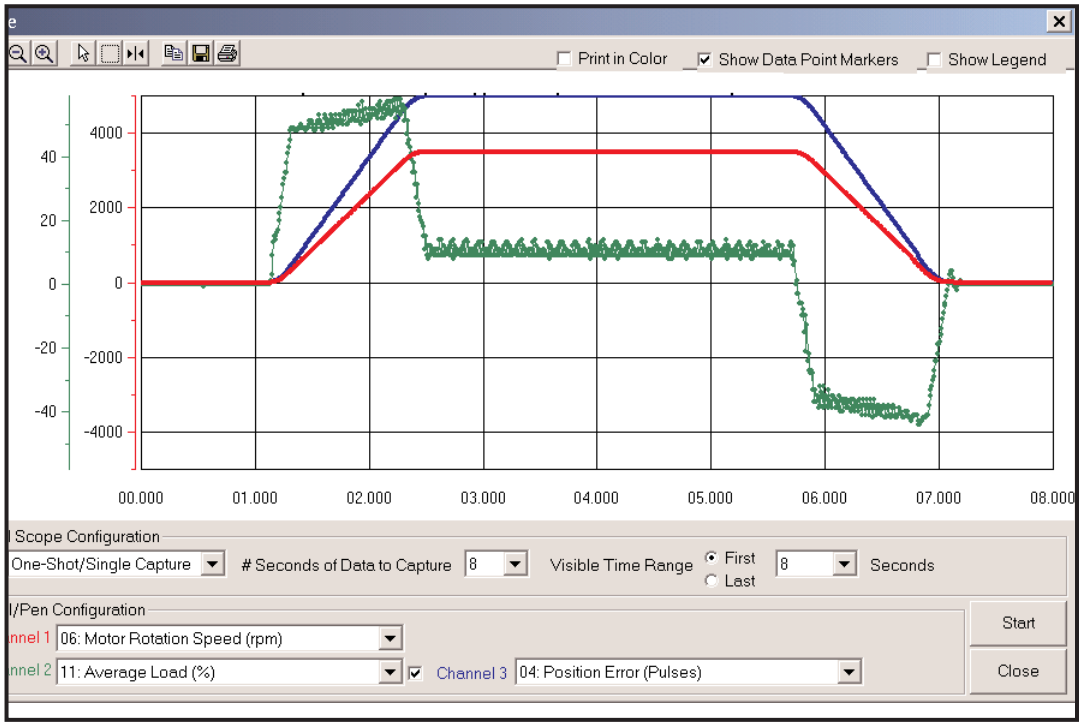
Tuning can be done with the help of the SureServo Pro software. Cable SVC-PCCFG-CBL is used to connect the PC with the servo.

For this action, go to the menu **Utilities>Current Config>Print Current Config.**

The next action is the tuning of the system, with any of the methods offered by the drive. The task here is to move the load without overshoots, from the home position to the three positions. In this case, only one position tuning is needed because the other 2 positions are basically the same movement.

The lead screw should be connected to the load in normal condition.

The first attempt to tune the system may result in behavior like that shown in the figure below.



The target of the tuning should result in a behavior such as the following figure: