

Application Note AN-SERV-002

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PRODUCT FAMILY: Sure Servo

Number: AN-SERV-002

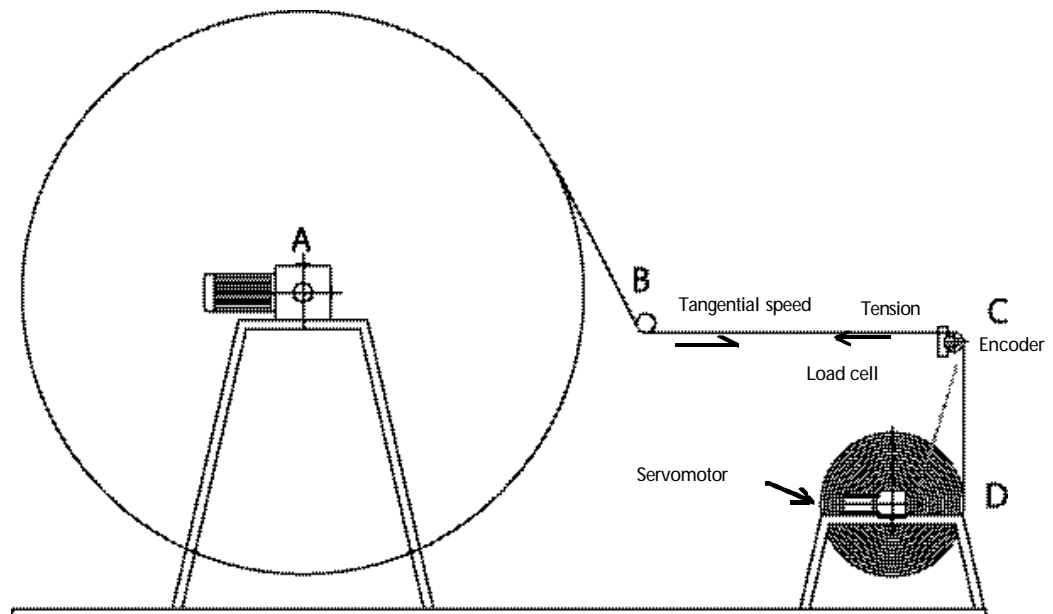
Subject: Torque control with a servo motor

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This example shows how we can control tension of a web using the torque control features of the servo system with the help of a PLC DL06.

The winder is a typical example of constant tension center winder control.



The diagram above represents a rewinder that makes the winding of plastics sheets at a constant web speed; In this case the right coil is the rewinder D, that will be wound at a constant speed of 328 feet/min, with a constant tension given by the torque supplied by the servomotor.

The unwinder (A) is controlled by other system, not shown here, to maintain the web speed constant to feed the rewinder, helped with the rollers B and C.

This simple example considers the assumptions and the steps necessary to define the drive system for a rewinder, that is, given the mechanical properties of the process, we will determine the size of the servo and the gear reducer, the signals to be exchanged between the process, the PLC and the servo drive through wiring diagram and explanations, the program on the PLC, the parameter configuration of the servo drive, and the expected operation. Tuning is not considered in this example.

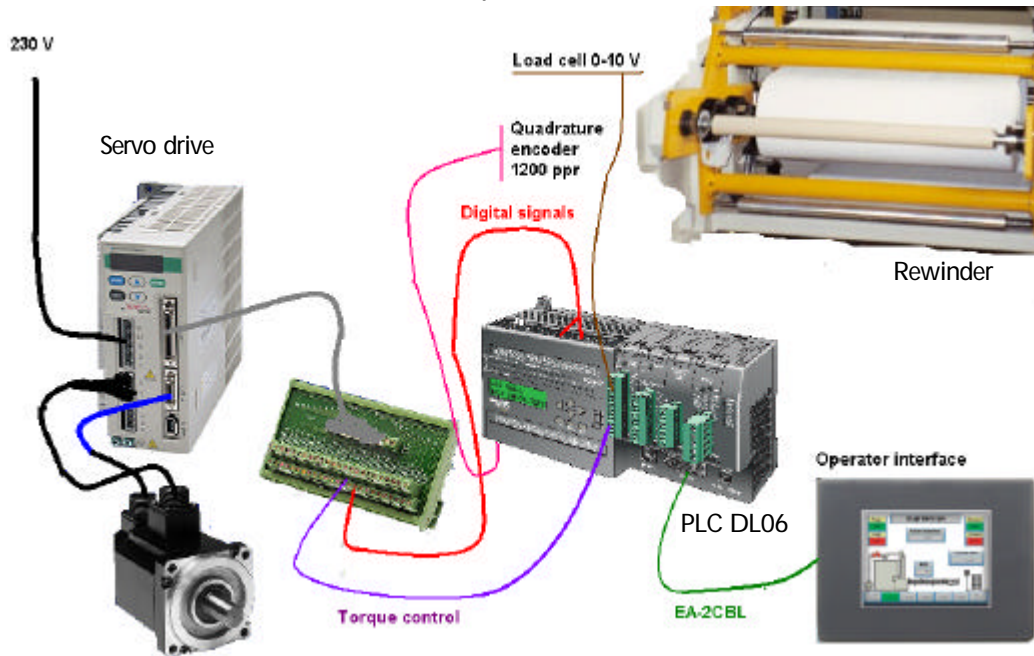
The motion drive system consists of a servomotor, whose size will be determined, and a reducer to move the shaft of the rewinder. Notice that the torque caused by the necessary tension, which is constant, varies with the radius of the coil.

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The torque to be supplied has to be calculated by a PLC DL06, that receives a linear speed signal from the encoder located on the roller, which has also a load cell to indicate the tension continuously. Notice that the web tension on the horizontal direction A-B is the same of the polyethylene on the direction from the roll C to the rewinder D.

The resistive torque should be the tension expressed in Newtons multiplied by the radius in meters, to get the resistive torque in Newton-meter.

The control system will consist of the servo, a PLC DL06 and a touch screen panel to input the desired PLI (pounds per linear inch, is in the range 0.5 to 1 PLI, the width of the spool (30 to 60 inches), the web speed is in the range 50 to 100 m/min; the control of the unwinder can be implemented on the PLC, but it is not described.



Determination of speed and torque of the rewinder

First, it is necessary to determine the speed and torque in the operation of the rewinder.

Let us consider that we have a rewinder for plastic sheets (polyethylene), with the following dimensions & features:

Roll

Core diameter	6 ¼ inches	159 mm
External diameter	30 inches	762 mm Max radius 0.381 m
Width of the winder	60 inches	1.52 m
Weight of the roll	1800 lb	818 Kg
Tension applied	1 PLI or	60 lb => 267.5 Newton
Feed speed	328 feet/minute	100 m/min => 1.67 m/s (A)

The winder begins to rotate in such a way that the feed speed increases from 0 to the feed speed in 50 seconds

The rotational speed of the winder is determined with the formula

$$w = v/r \quad (B)$$

being w the speed in radians/second, v the speed of the plastic sheet in [m/s] and r is the radius of the roll in meters

We have the following rpm of the rewinder

- When the roll is in the beginning the core determines the radius, which is very close to the diameter of the core.

$$w = 1.6667/0.1588 \times 2 = \text{approximately } 20.997 \text{ rad/s or } 200.51 \text{ rpm} \quad (C)$$

- When the roll is completed with 30 inches

$$w = 1.6667/0.762 \times 2 = 4.3745 \text{ rad/s or } 41.77 \text{ rpm} \quad (D)$$

This data allows us to determine the gear reducer to be used to drive the winder

Let us consider that a servomotor can deliver 3000 rpm.

Since the maximum rotational speed of the roll is 200.51 rpm according to (C), the theoretical ratio is 14.96 (3000/200.51). Looking at Shimpo Drives, their ABLE series gear reducers will work.

Let us select a ratio 15:1, frame size C, NEFAV, right angle (E)

What is then necessary to determine the torque?

We have to determine the running torque and the dynamic torque; for the dynamic torque we need to calculate the involved inertias:

The **core inertia**, easily determined as below

Inertia of the plastic core	0.513 [Kg-m ²] from below	
Inertia of the shaft holding the bobbin	2 [Kg-m ²] estimated	
Inertia of the reducer 0.415 [Kg-cm ²] or	4.15E-05 [Kg-m ²]	
The inertia of the motor	0 for now	
Total fixed inertia	2.513 [Kg-m²]	(F)

Calculus of variable inertia of the core, using the cylinder formula:

The inertia of a solid cylinder is

$$J = \rho \cdot (L \cdot r^4 \cdot \pi) / 2 \quad (G)$$

being ρ the density of the material

Width of the plastic core is	1.6 meter
External diameter of the core	0.158 meter
Internal diameter of the core	0.132 meter
Thickness of the walls	0 meter
Material of the reel core	Plastic
Density of material	2700 [Kg/m ³]
The thickness of the plastic web is	0.15 mm
Then the solid core inertia is	0.538 [Kg-m ²]
Let us remove the orifice	0.025 [Kg-m ²]

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Then total inertia of the plastic core is 0.513 [Kg-m²] (H)

The resistance due to the friction of the different parts.

For that, we will consider:

Reducer efficiency 95%

System efficiency 87%

Let us consider the inertias involved

Let us estimate the shaft inertia as 2 [Kg-m²]

Density of the plastic is determined as the weight divided by the volume

The volume is $V = (r_o^2 - r_i^2) * L * \pi$

This is 0.665 [m³]

The density of the web material is 1231 [Kg/m³]

Then we are ready to calculate the inertia, torque, rpm, etc. in function of the time.

In order to know how the radius will increase with the web, we can establish that the radius R(t) is the core radius plus the number of layers times the thickness of the web material. The number of layers is the distance of the web divided by the circumference or :

$$R(t) = \text{core}/2 + 2 * \text{thickness} * \text{distance}(t) / (2 * \pi * R(t))$$

rearranging the equation by multiplying by $2 * \pi * R(t)$ and moving all to one side

$2 * \pi * R(t)^2 - p * \text{core} * R(t) - 2 * \text{thickness} * \text{distance}(t) = 0$ we have the well known second degree equation. Since $x = (-b \pm \sqrt{b^2 - 4ac}) / 2a$, then the solution to R(t) is:

$$R(t) = (+\pi * \text{core} + \sqrt{\pi^2 * \text{core}^2 + 16 * \pi * \text{thickness} * \text{distance}(t)}) / (4 * \pi)$$

Applying these formulas to a table in Excel such us the following figure, we get the resulting partial main data:

T motor	Servomotor rpm	Radius[m]	
1.67[N-m] @ 39.56 rpm	593.40 rpm	0.0805@ 10 second	(I)
2.07[N-m] @ 159.60 rpm	2393.94 rpm	0.0997@ 50 second	(J)
7.80[N-m] @ 42.09rpm	631.37 rpm	0.378@1444 second	(K)

per calculations on the EXCEL spreadsheet, not shown here, for reason of space.

D1521 A1 =+PI()*\$F\$10*(4*PI())+SQRT(PI()*PI()*\$F\$10*\$F\$10+16*PI()*\$E\$50/1000*C1521)/(4*PI())												
A	B	C	D	E	F	G	H	I	J	K	L	
Time	speed m/s	distance[m]	radius	w[rad/s]	rpm	J[Kg-m ²]	Ttension	dw/dt	dJ/dt	T dyn[N-m]	Tmotor	
80	0	0.0000	0.000	0.0794	0.000	0	2.51	21.236	0	0	0.0000	1.6273
81	1	0.0333	0.033	0.0794	0.420	4.01	2.51	21.242	0.084	0.00	0.2113	1.6439
82	2	0.0667	0.100	0.0794	0.839	8.01	2.52	21.253	0.084	0.00	0.2114	1.6447
83	3	0.1000	0.200	0.0795	1.258	12.01	2.52	21.269	0.084	0.00	0.2116	1.6460
84	4	0.1333	0.333	0.0796	1.676	16.00	2.52	21.290	0.084	0.00	0.2118	1.6476
85	5	0.1667	0.500	0.0797	2.092	19.98	2.52	21.317	0.083	0.00	0.2121	1.6497
86	6	0.2000	0.700	0.0798	2.506	23.93	2.52	21.348	0.083	0.00	0.2125	1.6522
87	7	0.2333	0.933	0.0799	2.919	27.88	2.52	21.386	0.083	0.00	0.2129	1.6551
88	8	0.2667	1.200	0.0801	3.330	31.80	2.52	21.428	0.082	0.00	0.2135	1.6583
89	9	0.3000	1.500	0.0803	3.738	35.69	2.53	21.475	0.082	0.00	0.2141	1.6620
90	10	0.3333	1.833	0.0805	4.143	39.56	2.53	21.527	0.081	0.00	0.2147	1.6661
91	11	0.3667	2.200	0.0807	4.545	43.40	2.53	21.585	0.080	0.00	0.2155	1.6705
92	12	0.4000	2.600	0.0809	4.944	47.21	2.53	21.647	0.080	0.00	0.2164	1.6753
93	13	0.4333	3.033	0.0812	5.339	50.99	2.54	21.714	0.079	0.00	0.2174	1.6806
94	14	0.4667	3.500	0.0814	5.731	54.73	2.54	21.786	0.078	0.00	0.2184	1.6861

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1566	1485	0.3000	2405.467	0.3809	0.788	7.52	126.31	101.909	-0.018	0.03	-2.1904	7.6413
1567	1486	0.2967	2405.733	0.3809	0.700	6.89	126.33	101.914	-0.018	0.02	-2.1950	7.6413
1568	1487	0.2933	2405.967	0.3809	0.613	5.85	126.36	101.918	-0.018	0.02	-2.1990	7.6413
1569	1488	0.2000	2406.167	0.3810	0.525	5.01	126.37	101.922	-0.018	0.02	-2.2026	7.6413
1570	1489	0.1867	2406.333	0.3810	0.437	4.18	126.39	101.925	-0.018	0.02	-2.2055	7.6413
1571	1490	0.1333	2406.467	0.3810	0.350	3.34	126.40	101.927	-0.018	0.01	-2.2079	7.6413
1572	1491	0.1000	2406.567	0.3810	0.262	2.51	126.41	101.929	-0.018	0.01	-2.2098	7.6413
1573	1492	0.0667	2406.633	0.3810	0.175	1.67	126.42	101.931	-0.017	0.01	-2.2111	7.6413
1574	1493	0.0333	2406.667	0.3810	0.087	0.84	126.42	101.931	-0.017	0.00	-2.2119	7.6413
1575	1494	0.0000	2406.667	0.3810	0.000	0.00	126.42	101.931	-0.017	0.00	-2.2121	7.6413
1576	s	speed m/s	distance[m]	radius	w[rad/s]	rpm	J[Kg-m2]	Ttension	dw/dt	dJ/dt	T dyn[N-m]	Tmotor

It takes 1494 seconds or 24.9 [minutes] to complete the spool. (L)

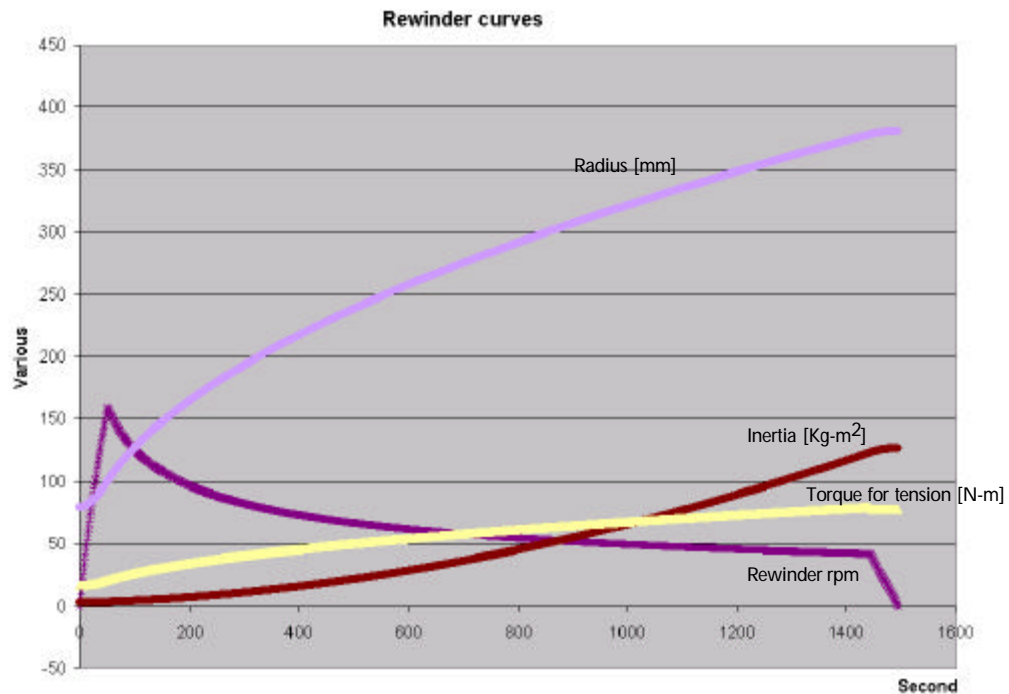
From these limit values, the necessary servomotor is a SVM-220B (2 kW), that provides continuous torque of 9.4 [N-m].

If the same calculations are done with the selected motor inertia, the results are

T motor	Servomotor rpm	Radius[m]
1.668[N-m] @ 39.56 rpm	593.39 rpm	0.0805@ 10 second (I')
2.07[N-m] @ 159.60 rpm	2393.94 rpm	0.0997@ 50 second (J')
7.80[N-m] @ 42.09 rpm	631.37 rpm	0.378 @ 1444 second (K')

Basically, in this case, the motor inertia does not have an effect on the results

See in the following chart the main characteristics of the movement.



The inertia at the beginning is	2.87[Kg-m2]referred to the load	
The inertia at the end is	126.78[Kg-m2]referred to the load	
The motor inertia referred to the load is	0.36[Kg-m2]	(M)
The inertia ratio is at the beginning	8.09	(N)
The inertia ratio is at the end	356.6	(O)

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PLC considerations:

Let us see now what is necessary on the PLC side:

Tension on the web

The tension on the web is measured with the load cell and delivered to the PLC with an analog signal 0-10 Volt, being the 10 Volt the span of the load cell device; typically 30% above the operating point. Since the required maximum tension is 267.5 [Newton], then the span will be 350 Newton in this example.

Let us see what is the PLC raw value for a measurement of 267.5 Newton (O)

$267.5/350 \times 10$ is 7.6428 Volt or in PLC raw value, $267.5/350 \times 4095 = 3129$. This should be the normal force of the tension measured on the load cell.

Measurement of the web speed

The PLC will receive the pulses of an encoder TRD-GK1200-RZD (1200 pulses per revolution). This encoder was selected to produce a pulse frequency close to the limit that the PLC can read. (More precision can be obtained if the module H0-CTRIO is used, since it can read up to 100 kHz, together with an encoder that has a larger number of pulses per revolution, for example 5000 ppr, and/or a smaller diameter roller C). We will calculate the speed every 50 [ms], to make the PID sample work at the same period. We will count the number of pulses every 50 [ms]. This will allow to determine the tangential speed of the web.

Let us say the roller C has a diameter of 100 mm. Then the typical rotational speed will be $1.667[\text{m/s}]/(\pi \times 0.100 \text{ m})$ [cycles/s] by the formula (B). This results in approximately 5.30 cps, or $1200 \times 5.30 = 6366$ pulses per second, since each revolution of the encoder produces 1200 pulses, or 318 pulses every 50 [ms] (P)

Determination of the spool speed

The spool speed, which is proportional to the servomotor speed, can be read from the analog output of the servo (or the digital value in the memory if using MODBUS, address 0002_h, if the parameter P0-02 is configured as 06, actual motor velocity).

Let us check what is the calculated speed on the PLC at a servo motor rotation of 2393 rpm, (assuming that the servo is calibrated to deliver 8 [Volt] at 3000 rpm), the servo can generate then $2393/3000 \times 8$ [V] = 6.381 Volts. This is interpreted as $6.381/10 \times 4095 = 2613$ counts on the scale 0-4095 (note that there are some error of truncation).

Determination of the radius

The external radius of the web spool can be calculated with the following relation:

The tangential speed is $v = w/r(t)$, from formula (B); since the magnitude v can be calculated with the counts of the encoder pulses, and the servomotor speed is calculated by the servo, the radius $r(t)$ at any time is w/v times a constant.

We know that the radius at this time is 99.7 mm (from (J)). Therefore, the quotient $318/2613$ with a constant should be equivalent to 99.7 [mm].

The constant is then: $99.7 = K1 \times 318/2613 \Rightarrow K1 = 99.7 \times 2613/318 = 819.233$

Having this constant, at a servo motor rotation of 631.37 rpm, the servo can generate $631.37/3000 \times 8 = 1.683$ Volts. This is interpreted as $1.683/10 \times 4095 = 689.4$ counts on the scale 0-4095. The number of counts on the encoder counts will be 318 if the speed is 100 m/min. then the radius will be $K1 \times 318/689.4 \Rightarrow 377.78$ mm. In fact, per the more exact calculation on EXCEL, the radius will be 378.1 mm. This is an error of $(378.1 - 377.78)/378.1 \Rightarrow 0.084\%$, which is acceptable for this purpose.

There are other errors of truncation, but the error does not seem to be above 0.5%
The calculation of the radius is important, to work with the torque. Recall that the load cell measures only tension.

The web tension has to be maintained constant by the application of a torque by the servo motor . This torque can be controlled with a PID function already built in the PLC DL06. The operator will enter the desired PLI and the PLC will calculate the necessary torque using the calculated radius.

The PID table initial register in this example is V10000.

Torque setpoint of the PID loop.

The PLC has to generate the torque setpoint signal and the command to start the operation.

The set point for the torque then will be given by the desired tension multiplied by the radius (function of time). In this case, let us recall that the PLC tension is 267.5 Newton, and the measurement of this value results in a PLC raw value 3129, per (O). This is the maximum tension that the machine will deliver. Of course, the operator can adjust the PLI value to a lower value. This value is multiplied by the radius on the PLC to generate the setpoint to the servo.

This value is entered in the algorithm of the PID on the address V10002 as a decimal number format.

Torque on the process variable of the PID loop.

The PLC has to generate the corresponding torque signal for the process variable that is indirectly obtained when measuring the tension with the load cell .

The process variable torque then will be given by the measured tension multiplied by the radius (function of time).

This value is entered in the algorithm of the PID on the address V10003 as a decimal number format.

Control output of the PID loop (torque to be delivered by the servo).

The PLC has to generate the corresponding signal for servo to apply the proper torque to maintain the tension constant.

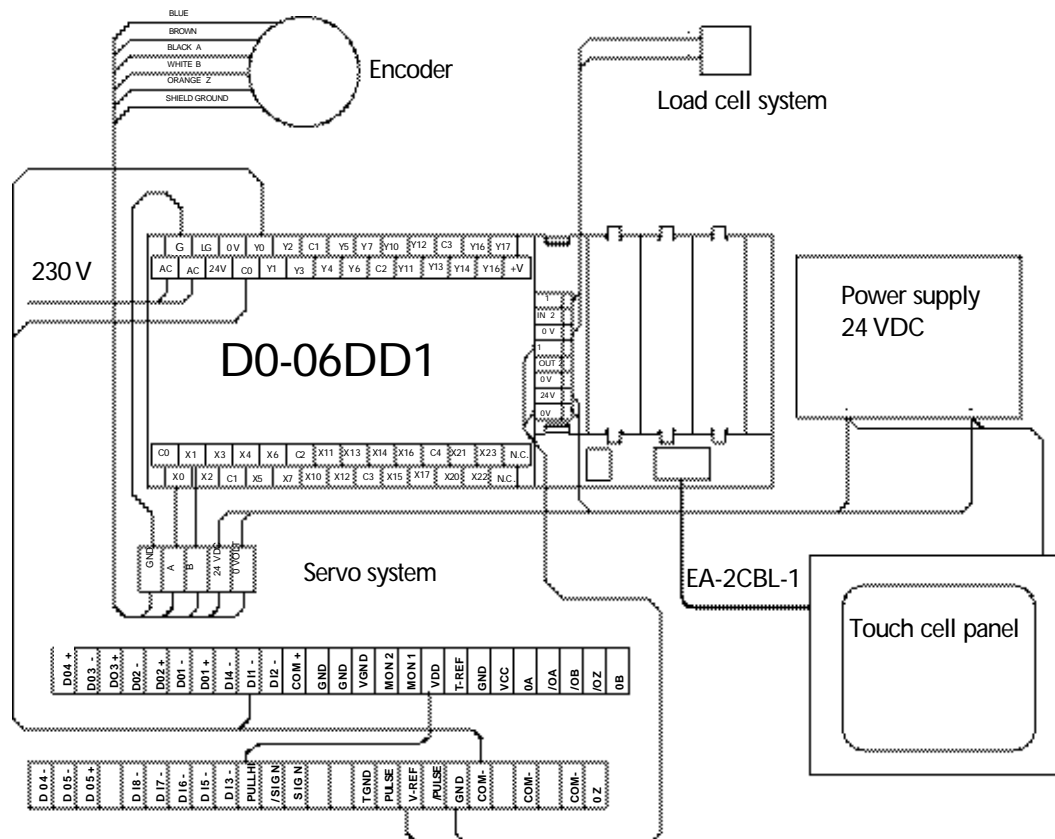
The PID algorithm will generate an output in the range 0-4095 in decimal format that will be sent with an analog signal of 0 - 10 Volt on the terminal T-ref.

In order to scale this properly, we consider:

The maximum torque that the servomotor will supply can be 9.4 [N-m]; this will be our 100%.

7.8 [N-m] is 82.98% of the full torque of the motor; then the output on this condition is in PLC raw value a figure of 3397. This will allow us to scale the output properly. Of course the Servo can and must deliver more torque if the system requires it... On the initial operation, however, the servo requires a lot less torque than this figure, and for example at 50 seconds of operation, the required torque is only 2.07 [N-m]. This concept is used on the ladder diagram, where there are more explanations.

As we can see from the figure on page 2, the operator will have a touch screen panel, from where it is possible to define the web speed, the value of the PLI, the width and final radius of the spool, and give the commands to start. The rewinding should stop automatically when the final radius is reached.

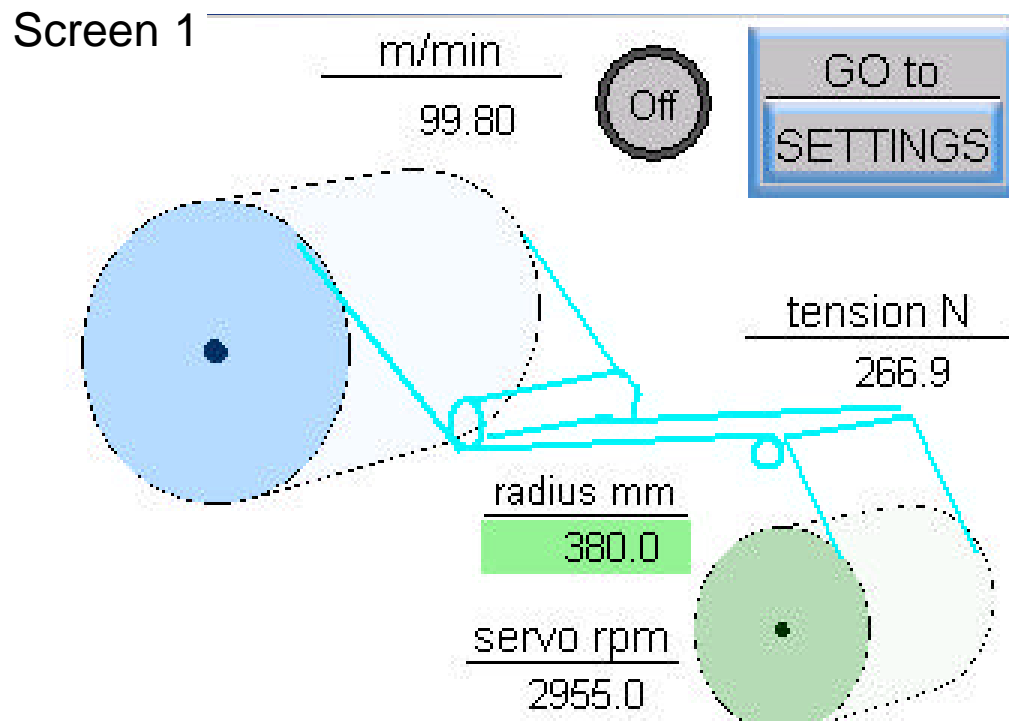


The touch panel is the operator interface. This panel requires 24 VDC, together with the encoder, the analog I/O module and probably the load cell system, depending on the vendor selection.

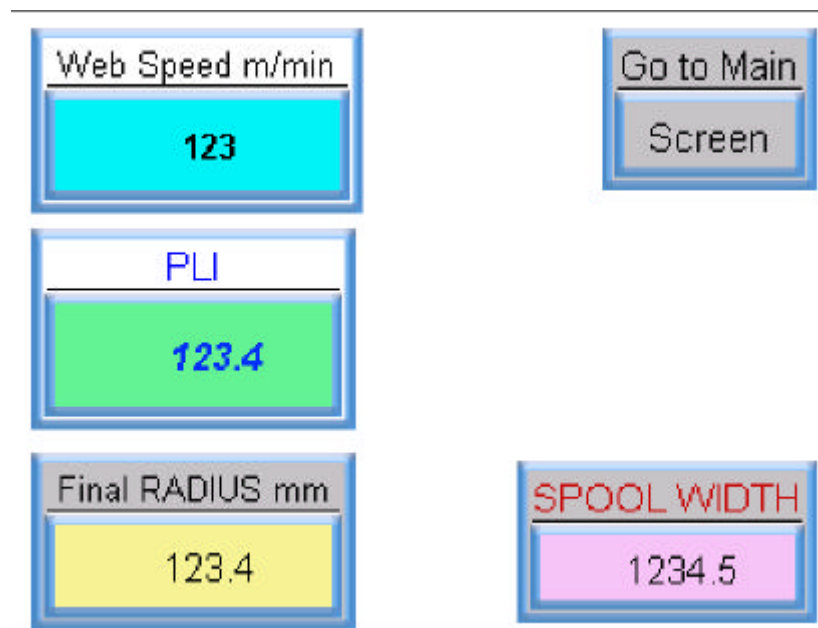
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For this example we have selected a panel EA7-T6C, and the PLC is a D0-06DD1.
Let us work on the project of the touch screen:

We will create, for now, 2 screens; one if for the visualization of the process and the other are the initial settings. See the screens on the figure below:



Screen 2



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As a convenience for the programming, we have selected to use floating points numbers for the numeric displays and entries

These are the tags created:

RADIUS	Floating PT 32	V5000	DEV001
WIDTH	Floating PT 32	V5002	DEV001
PLI	Floating PT 32	V5004	DEV001
TENSION	Floating PT 32	V6000	DEV001
LINEARSPEED	Floating PT 32	V6002	DEV001
SERVO SPEED	Floating PT 32	V6004	DEV001
CALC.RADIUS	Floating PT 32	V6010	DEV001
START	Discrete	C100	DEV001
WEB SPEED	Floating PT 32	V5010	DEV001

This deserves some explanations:

RADIUS on V5000 is the desired radius input by operator on the settings screen

WIDTH on V5002 is the desired width of the web, set on the settings screen

PLI on V5004 is the desired tension input by operator, in pounds per inch.

WEB SPEED on V5010 is the desired speed, set on the settings screen

The other tags are the measured or calculated value, to be displayed on the screen

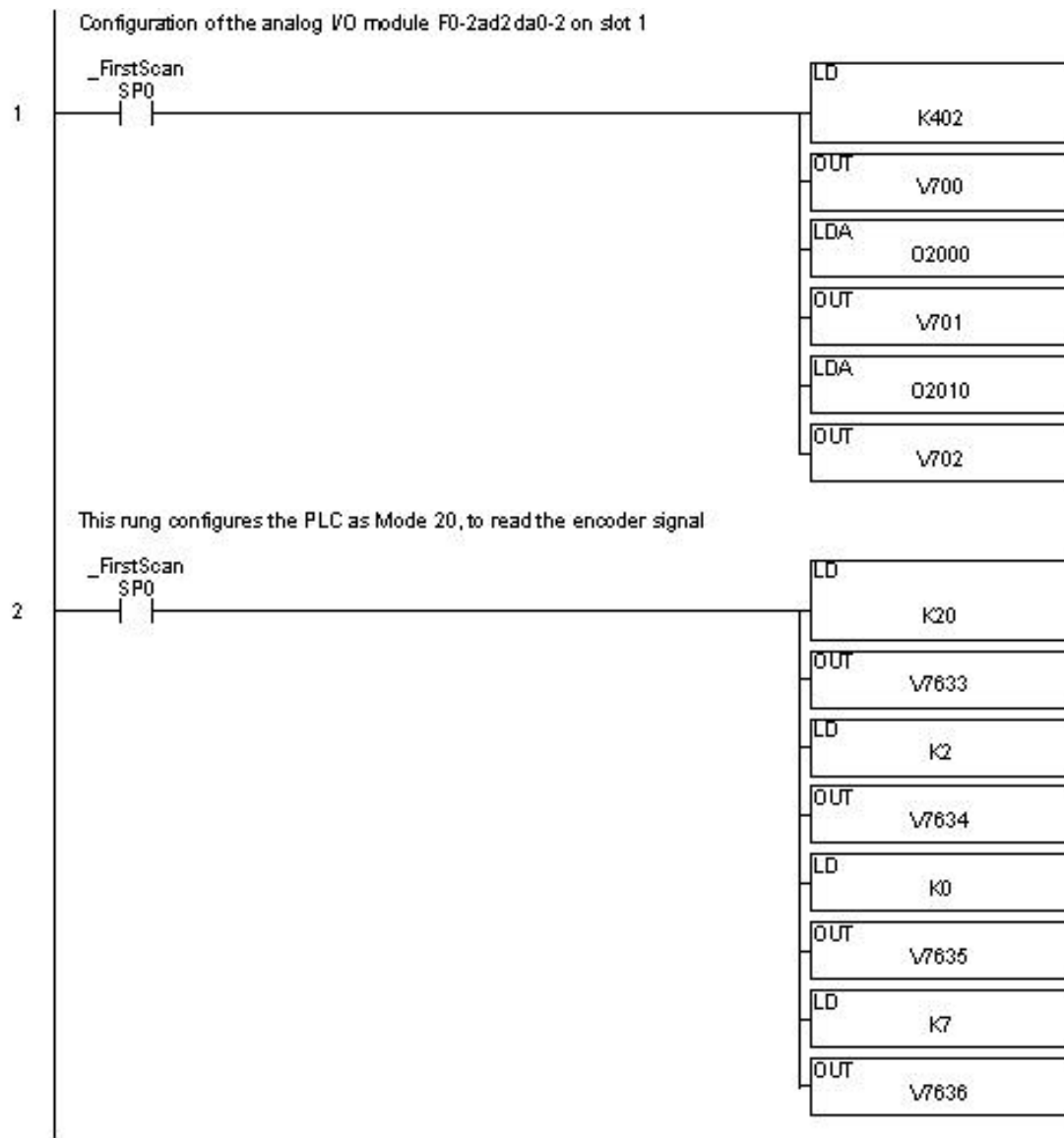
The PLC D0-06DD1 will have an analog module F0-02AD2DA-2 on slot 1.

The PLC will read the input data, process the information, execute the PID loop, and then write the outputs to the corresponding registers.

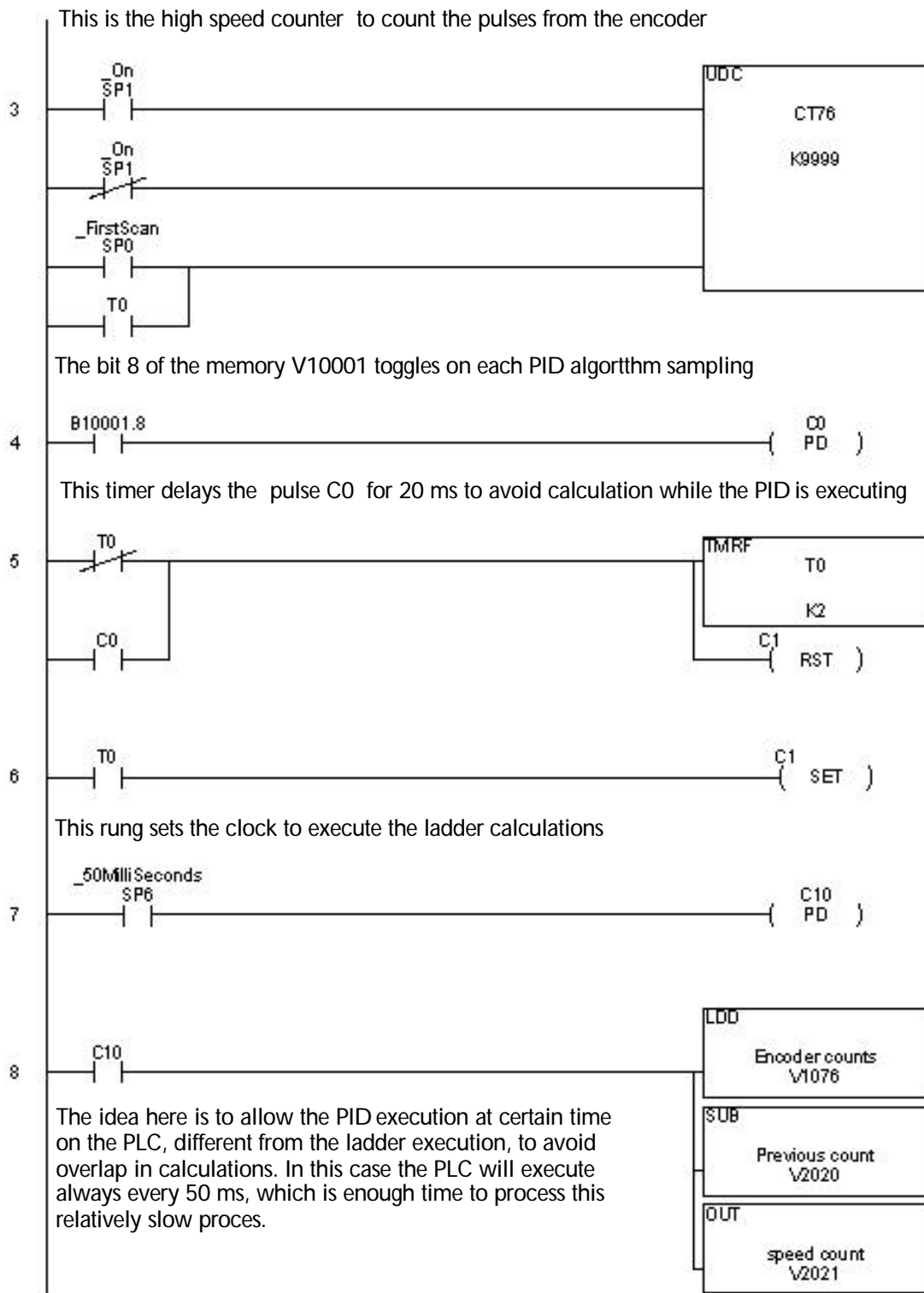
The next step is to create the PLC program.

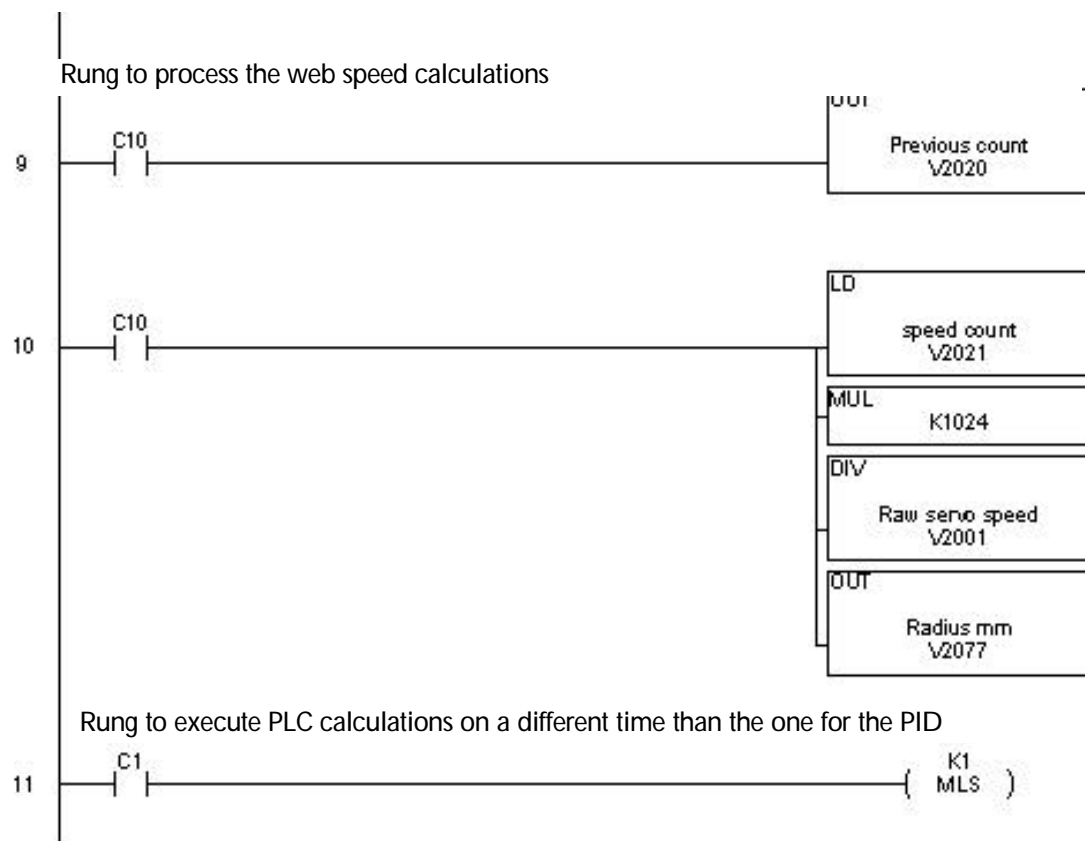
The PID loop is created with the PID table beginning on address V10000.

More explanations are given in the comments of the ladder diagram.

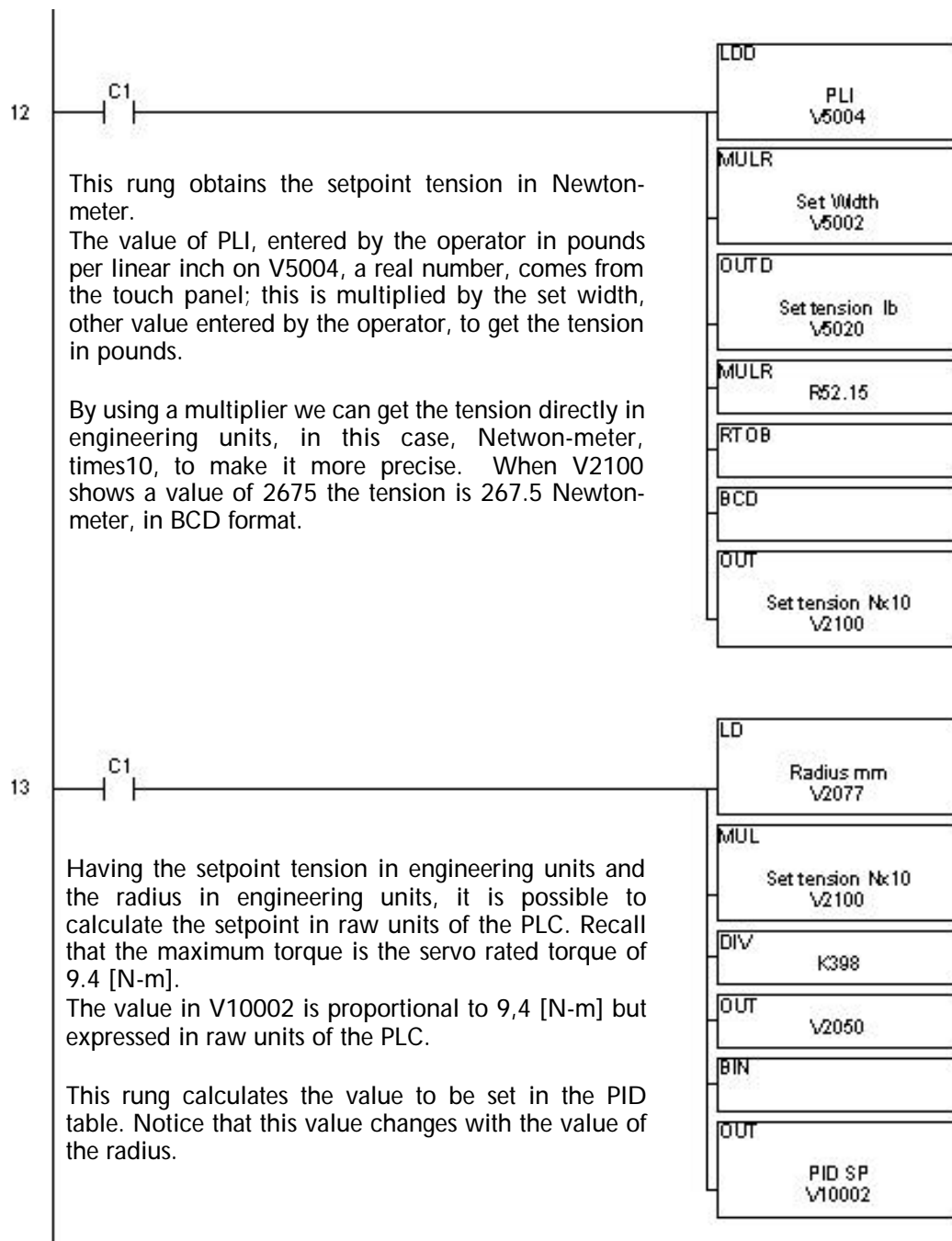


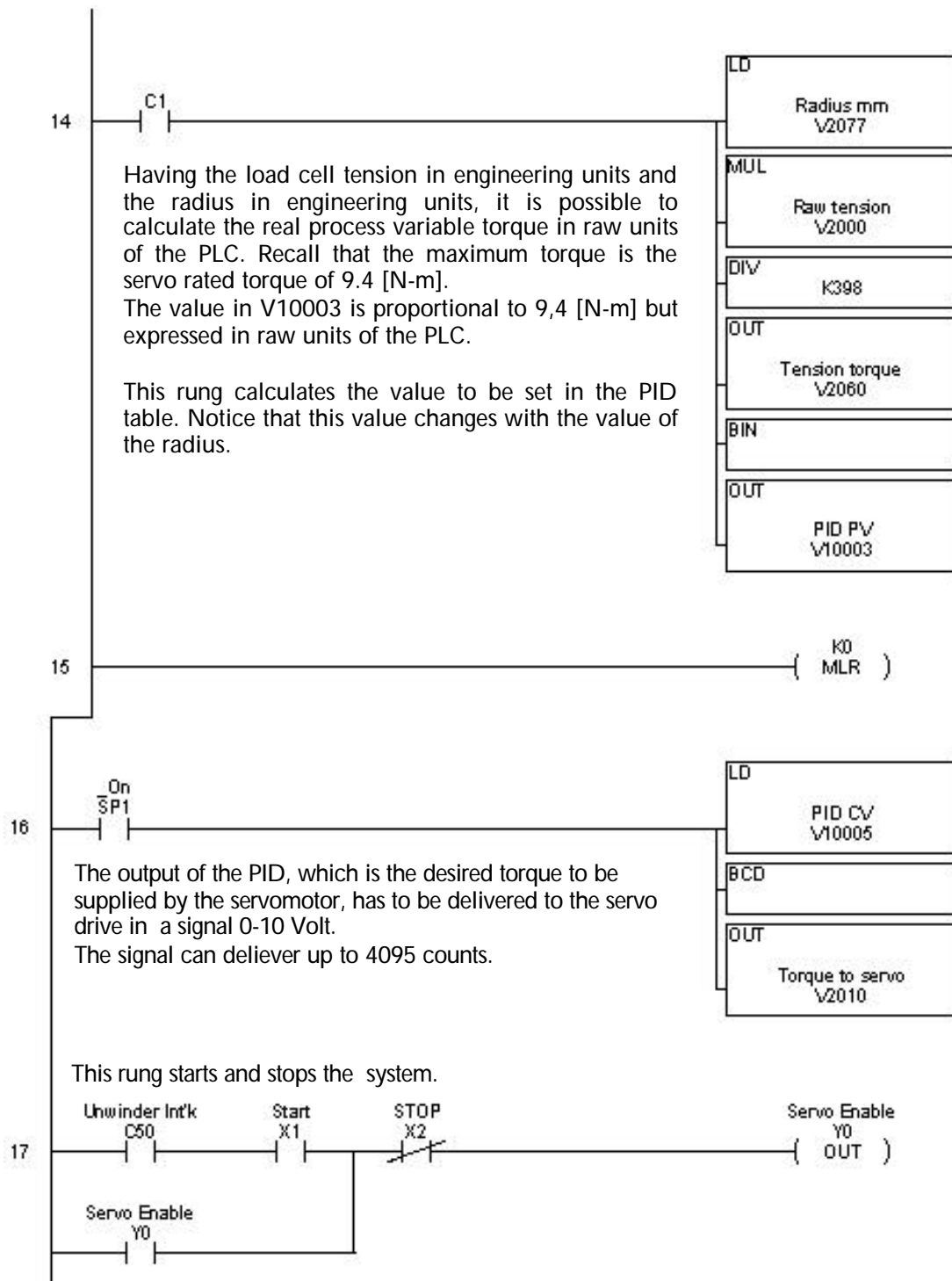
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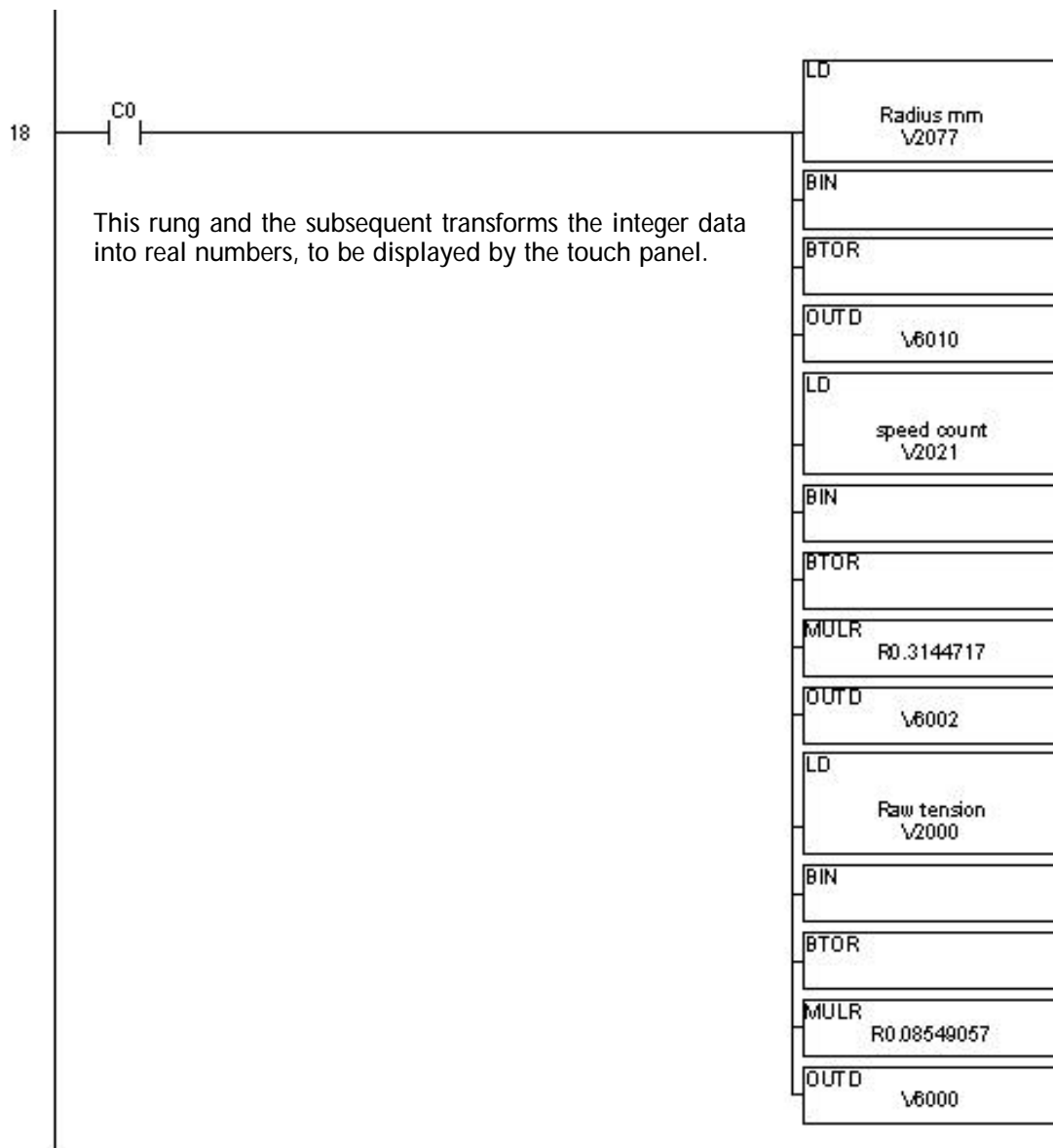


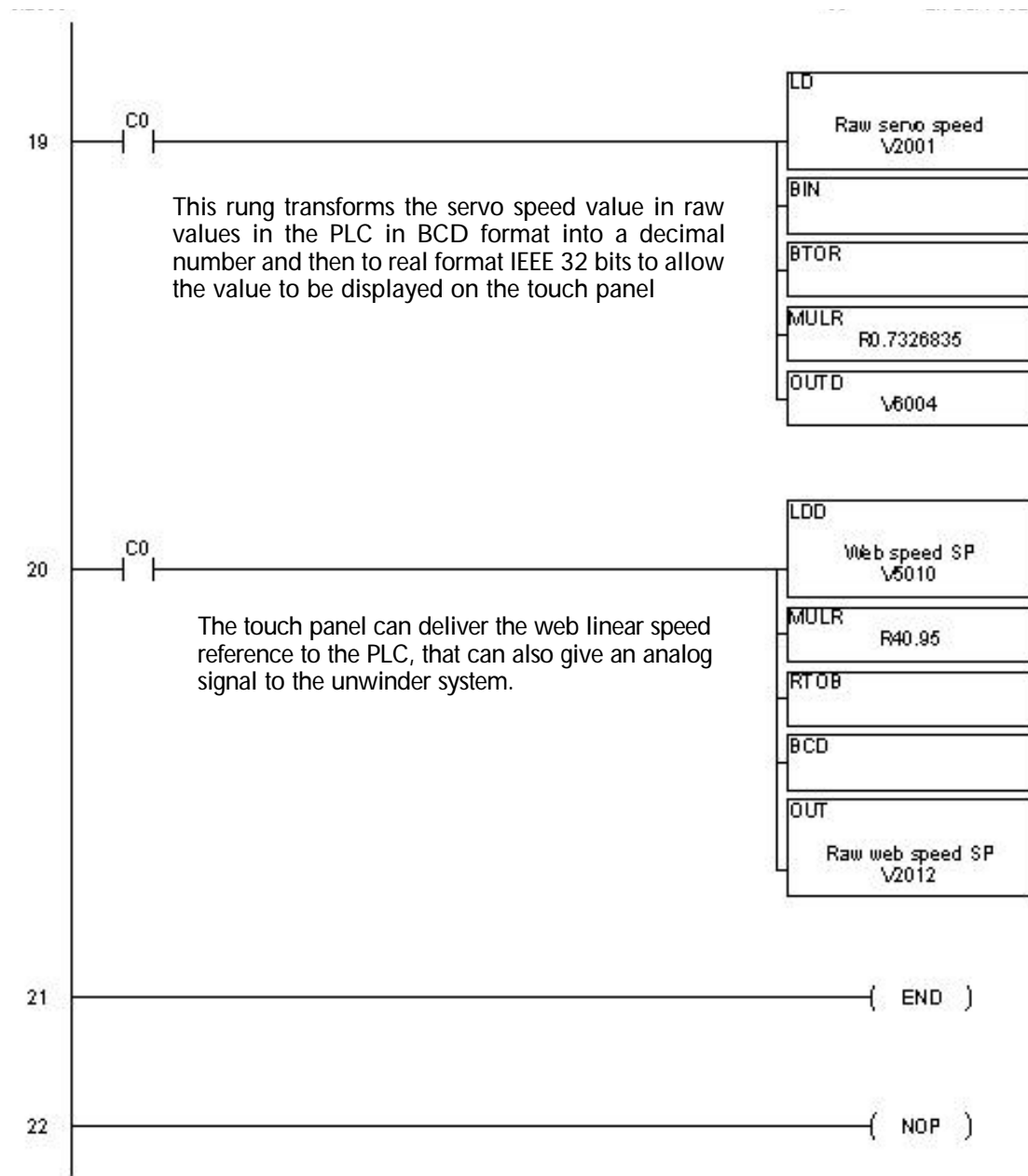


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Parameter settings for the drive

P 0.02	Drive status	Setting: 06
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Range: 0 -16

We are selecting here to display the actual motor velocity in rpm

P 1.01	[3] Control mode and output direction	Setting: 0103
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Range: 0 to 1110

We are selecting here Torque control mode with CW direction and digital I/O set to retain previous settings on power off.

P 1.02	[2] Velocity limit	Default Setting: 0001
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Range: 0 to 11

We are selecting here to enable the velocity limits.

P 1.31	[5] Motor code	Setting: 30
---------------	-----------------------	-------------

Range: 10, 11, 12, 20, 21, 22, 30, 31

We are selecting here the motor SVA-220B, 2 kW, with brake; brake is to hold the spool when the web should be threaded.

P 1.32	Motor stop mode selection	Setting: 0
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Range: 00, 01, 10, 11

We are defining here to stop with dynamic braking.

P 1.37	Inertia mismatch ratio	Setting: 4.2
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Range: 0 - 200.0

We are defining a value of 4.2, per the calculations done earlier on (O).

P 1.47	Homing mode	Setting: 0
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Range: 0 - 1,225

We are defining here to disable the Home position.

P 1.52	Regenerative resistor value	Setting: 20
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Range: 10 - 750 Ohms

We are selecting here 20 Ohms. This is done automatically if not external resistor is added.

P 1.53 Regenerative resistor capacity Setting: 120

Range: 30 - 1000

We are selecting here 120 Watt. This is done automatically if not external resistor is added.

P 1.55 Maximum velocity limit) Setting: 3000

Range: 0 - 5,000

We are defining here the servomotor absolute velocity limit.

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 Y1 of PLC

P 2.11 Digital input Terminal 2 (DI2) Setting: 0

Range: 0 - 145

We disabled this input.

P 2.12 Digital input Terminal 3 (DI3) Setting: 0

Range: 0 - 145

We disabled this input.

P 2.13 Digital input Terminal 4 (DI4) Setting: 0

Range: 0 - 145

We disabled this input.

P 2.14 Digital input Terminal 5 (DI5) Setting: 0

Range: 0 - 145

We disabled this input.

P 2.15 Digital input Terminal 6 (DI6) Setting: 0

Range: 0 - 145

We disabled this input.

P 2.16 Digital input Terminal 7 (DI7) Setting: 0

Range: 0 - 145

We disabled this input.

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P 2.17	Digital input Terminal 8 (DI8)	Setting: 0
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Range: 0 - 145
We disabled this input.

P 2.18	Digital output Terminal 1 (DO1)	Setting: 0
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Range: 0 - 109
We disabled this output.

P 2.19	Digital output Terminal 2 (DO2)	Setting: 0
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Range: 0 - 109
We disabled this output and the other outputs.

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 setting on all the parameters, we recommend to print the parameters with the help of the Sureservo Pro software.

In order to check that the PLC was wired correctly to the servo drive, use the parameter P4-07 to see the status of the inputs; use parameter P4-09 to see the status of the servo drive outputs.

The tuning can be done with the help of the SureServo Pro software: The standard white cable SVC-PCCFG-CBL is used to connect the PC with the servo. We recommend to connect the drive at the rate of 115 kBaud.

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

For this action, go to the menu **Utilities>Current config>Print current config**

The development of the control is not exact or complete, since the effects of air entrainment and radial pressure, as well as the possible tapered tension are ignored.

In any case, this paper shows mostly the concepts to apply the sure servo to the rewinder.