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Direct Logic 405

16 Loop PID Coprocessor

F4-16PID

Order Number: F4-16PID-M

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CHAPTER 1: INTRODUCTION

General Description

The Direct Logic 405 Proportional Integral Derivative CoProcessor (PIDCOP) executes up to 16 PID loops independent of the DL405 CPU. Using the high speed parallel dual port RAM (intelligent module shared RAM) interface, the PIDCOP reads the Process Variable (PV) and directly writes the PID output into V-Memory.

Since minimal supporting ladder logic is required, the floating point math intensive PID calculations in the CoProcessor will have little effect on CPU scan time.

Transmitters

Using standard DL405 I/O modules to interface to field transmitters maintains application flexibility without additional cost burden in the PIDCOP. Normally the PV is obtained from a 4-20 mA current loop or an analog voltage (various ranges). Specialty modules are available for direct connection of both T/C and RTD's. Rate and pulse type PV inputs (flow) are within the capabilities of the 405 High Speed Counter.

Actuators

Output of the PID algorithm may be used to directly control an actuator such as a current loop controlled valve. Using minimal additional ladder logic both time proportioning (eg. heaters for temperature control) and position actuator (e.g. reversible motor on a valve) type control schemes are easily implemented.

Easy Loop Programming

Since all loop parameters are stored in V-Memory, programming may be accomplished in several ways. An intelligent Operator Interface Terminal (OIT) or industrial computer connected to either port on a 405 CPU can load loop parameters into V-Memory. A single OIT can service one or several 405 systems using the 25 pin ***Direct*NET** network port on the 405 CPU.

Simple Setpoint Adjustment

The setpoint in V-Memory may be changed via the MIU or an attached OIT. Using minimal additional ladder logic, both ramp and soak may be implemented for setpoint changes.

Operation Specifications	
V-Memory Block	A unique V-Memory location specifies the starting address of the block of V-Memory to be used by the PIDCOP. Up to 5 PIDCOPs may be used with a single 405 CPU. PIDCOPs must be installed in the CPU base.
Number of Loops	Up to 16 independent PID loops for each PIDCOP. A unique V-Memory location specifies the number of loops which are enabled for each PIDCOP.
PID Algorithm	Position or velocity form of the PID equation. Optionally specify direct or reverse acting, square root of the error, and error squared control.
Sample Rate	Specify the time interval between PV samples, .1 to 999.9 in units of seconds or minutes.
Auto / Manual	A control relay, CR, which when energized places the corresponding loop into automatic mode. PV alarm monitoring continues when loops are in manual or off mode.
$\sqrt{PV}$	Specify a square root of the PV for a flow control application.
Limit SP	Specify a high and low limit for allowable setpoint changes.
Scaling	Conversion of the PV value to engineering units is done in an operator interface program such as PID Commander™.
Gain	Specify proportional gain of 0.00 to 100.0. A value of 0 disables the proportional term.
Reset	Specify reset time of 000.1 to 999.9 minutes, seconds, milliseconds or microseconds. A value of 999.9 disables the integral term when the reset units is minutes.
Bumpless Transfer I	Bias and setpoint are initialized automatically when the PIDCOP is switched from manual to automatic. This provides for a bumpless transfer. Setpoint = PV Bias = Output
Bumpless Transfer II	Bias is set equal to the Output when the PIDCOP is switched from manual to automatic. This allows switching in and out of automatic mode without having to reenter the setpoint. Bias = Output
Limit Output	Optionally specify maximum and minimum output values.
Step Bias	Provides proportional bias adjustment for large setpoint changes. This may stabilize the loop faster and reduce the chance of the output going out of range. Step bias should be use in conjunction with the normal adjusted bias operation.
Anti-windup	If the position form of the PID equation is specified, the reset action is stopped when the PID output reaches 0 or 100%. Select adjusted bias or freeze bias operation.
Rate	Specify the derivative time, 0 to 99.99 in units of minutes or seconds. A value of 0 disables the derivative term.

Rate Limiting	Specify a derivative gain limiting coefficient to filter the PV used in calculating the derivative term (99.99 to 00.01).
Error Deadband	Specify an incremental value above and below the setpoint in which no change in output is made. Deadband around the setpoint does not need to be uniform and may be different than the PV yellow deviation.
Error Squared	Squaring the error minimizes the effect a small error has on the Loop Output, however, both Error Squared and Error Deadband control may be enabled.
20% Offset of PV	Specify a 20% Offset of the PV to input a 4-20 mA transmitter using a 0-20 mA analog input module range. This is normally used to permit Broken Transmitter monitoring. A 20% Offset of the PV is also specified when 0-5 V dc and 4-20 mA signals are input with the same analog module.

Alarm Specifications	
Deadband	Specify .1% to 5% alarm deadband on all alarms except Rate of Change.
PV Alarm Points	A Y output or CR may be activated based on four PV alarm points (Low Low, Low, High, and High High alarm points).
PV Deviation	A Y output or CR may be activated based on four PV deviation points. Specify an alarm for PV deviation above or below the setpoint (Yellow Deviation) and an alarm for greater PV deviation from the setpoint (Orange Deviation).
Rate-of-Change	A Y output or CR may be activated when the PV changes faster than a specified rate-of-change limit.
Broken Transmitter	Monitor the PV for a broken transmitter. The Broken Transmitter Alarm is set if the PV is less than 2.4 mA. This alarm is effective when a 4-20 mA transmitter is used with a 0-20 mA analog input range and the 20% Offset of PV operation is selected.

Hardware Specifications	
Mounting Requirement	Single slot in CPU base, up to five modules per system
Environment	0^{o}C to 60^{o}C (32^{o}F to 140^{o}F), 5 to 95% humidity (non-condensing)
Power Required	160 mA at +5 V dc Maximum from base power supply (no external)

CHAPTER 2: PID COMMANDER™ LOOP PROGRAMMING

PID COMMANDER

PID Commander for DOS is an easy to use Operator Interface program for PCs and compatible industrial work stations. PID Commander greatly simplifies PID CoProcessor configuration, tuning and operation.

PID Commander directly accesses the PID CoProcessor loop tables in V-Memory. The PID Commander software is used for loop configuration, documentation, tuning and operation. PID Commanders other features include scaling of the Process Variable to engineering units and documentation generation.

INSTALLATION

1. Insert the PID Commander disk into either the A: or B: drive.

2. At the DOS prompt enter:

   A: or B: INSTALL

RUNNING PID COMMANDER

1. Connect a cable to the 405 CPU. This may be either a programming type cable connected to the 15 pin DIRECT programming port, or a networking type cable connected to the 25 pin HOSTLINK or *Direct*NET network port.

2. Change to the PID Commander directory.

   C: CD\PID

3. For a monochrome monitor, enter PIDMONO. If you have a EGA or VGA color graphics adapter and a color monitor, enter PIDCOLOR.

4. To display additional command line switch options enter PIDCMDR ?.

5. If PID Commander fails to establish communication with the PLC CPU, go to OFFLINE mode and edit the PORT SETUP. You must have the correct PROTOCOL (see step 1 above) and NETWORK ADDRESS selected. PID Commander will determine the other parameters automatically. To display the 405 CPUs NETWORK ADDRESS:

   Using an MIU press AUX 56 ENT ENT.

   Using PLC CPU programming software, enter the AUXILIARY FUNCTIONS page and view SETUP SECONDARY ADDRESS.

   Once the PORT SETUP is correct, retry communication by selecting STATUS, ONLINE and then press ESC.

6. If prompted for the MODULE SETUP information, enter the slot number in the CPU base where the PID CoProcessor is installed (0-7). Enter the starting V-Memory address of the loop table. The example ladder logic provided on the PID Commander disk works with an address of V5000. Any user V-Memory location may be specified.

CONFIGURING LOOPS

1. Press the Enter key to edit the loop title. Press ESC or Enter again when done.

2. Use a password if you wish to restrict access to the loop tuning when using the run time version of PID Commander, PIDCRUN.EXE.

3. Cursor down through the configuration screen and press Enter to edit any of the items shown in the top center box. Help text for the items shown is displayed in the bottom center box.

4. Press page down to access additional ALGORITHM DATA.

5. At any time press either F4 or F5 to view the values for other loops.

PRINTING LOOPS

Changes made to the SETUP PRINTER screen are saved to disk by repeatedly pressing the ENTER key until the main menu returns. Pressing the ESC key will cancel any changes made.

Configuration: Specify the number of rows per page in the range 50-999.

Specify the number of columns per page in the range 80-132.

Specify if a form feed character or multiple carriage return/line feeds are to be sent to the printer at the end of a page.

If your printer automatically adds a line feed character after each carriage return then select no for LF with CR.

Specify a file name without a path if the print out is directed to a file.

Optionally, use the last line to send an ESC sequence or other control characters to the printer. Values are entered in hexadecimal.

Execution: Select EXECUTE PRINT to print out the loop data for all loops defined in the currently selected loop file.

TUNING LOOPS

Use F4 and F5 or the arrow keys to highlight the loop you wish to tune. Changes made on the loop tuning page are immediately made in the PLC as well. Only PV alarms which have been enabled may be edited. The values displayed are continually read from the PLC.

OPERATING LOOPS

The loop operation page simultaneously displays the PV, SP, OUTPUT and alarm status for four loops. Use F4 and F5 or the arrow keys to highlight the loop you wish to edit. Press F2 or ENTER to edit the currently selected loop. To change the loop OUTPUT, the loop must be in manual mode. The ASCII character based bar graphs provide a convenient visualization, however, for greater accuracy, refer to the digital values.

CHAPTER 3: SUPPORTING LADDER LOGIC

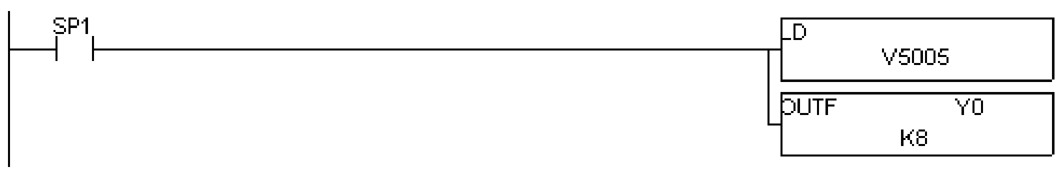
Minimal ladder logic is required in most applications. The following ladder logic examples extend the capabilities of the PIDCOP.

AUTO/MANUAL MODE CONTROL

The rung of ladder logic below simply masks X0 into the manual mode and X1 into the automatic mode bit position of the mode word for loop 1 (V5000).

ALARM WORD DECODING

The rung below copies the alarm bits for loop 1 (V5005) into Y0-Y7.



Y0	Low Low PV Alarm
Y1	Low PV Alarm
Y2	High High PV Alarm
Y3	High PV Alarm
Y4	PV Orange Deviation (Orange > Yellow)
Y5	PV Yellow Deviation
Y6	Rate-of-Change Alarm
Y7	Broken Transmitter Alarm

READING THE PV AND WRITING THE LOOP OUTPUT

The Process Variable (PV) may be written from an analog input module directly into the loop table. The Loop Output may be written directly to an analog output module. Please see Appendix B for examples of reading and writing FACTS analog modules, F4-08AD and F4-04DA.

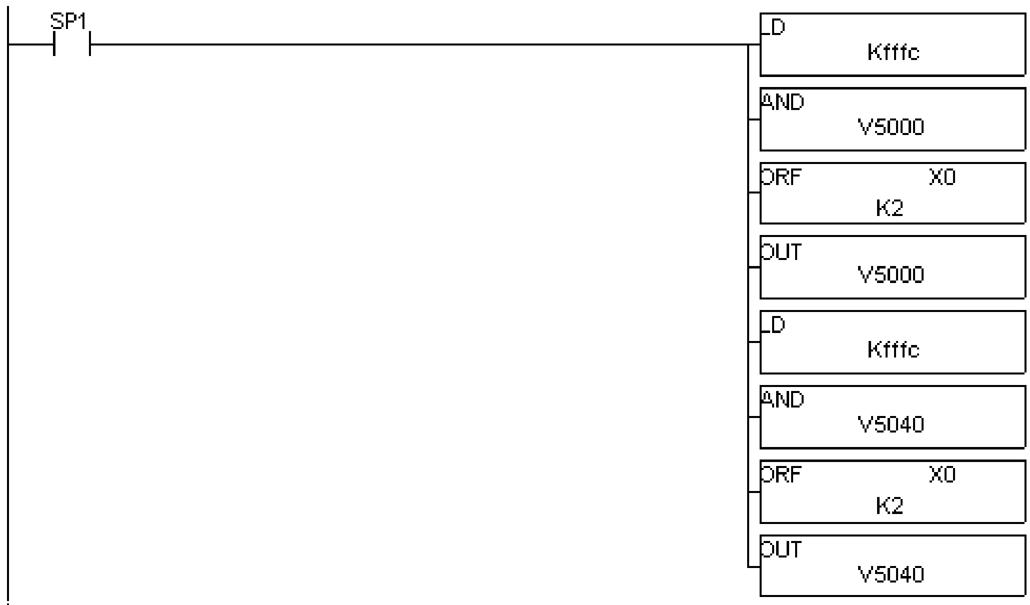
CASCADING LOOPS

A Cascaded loop has a setpoint which is the output of another loop.

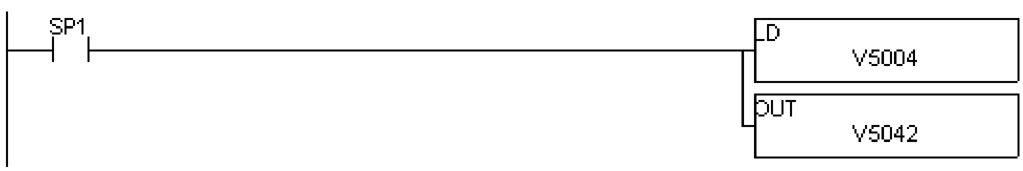
If any loop in a cascade is placed in Manual mode, then all other loops in the cascade must be placed in Manual to prevent reset windup.

The following example cascades loops 1 and 2. More than two loops may be cascaded by extending the example. The example is for a loop table beginning at V-Memory address V5000.

A single input, X0, is used to place both loops in MANUAL mode. Turning on X1 with X0 off will place both loops in AUTOMATIC mode.



The output of loop 1 is written to the Setpoint location for loop 2.



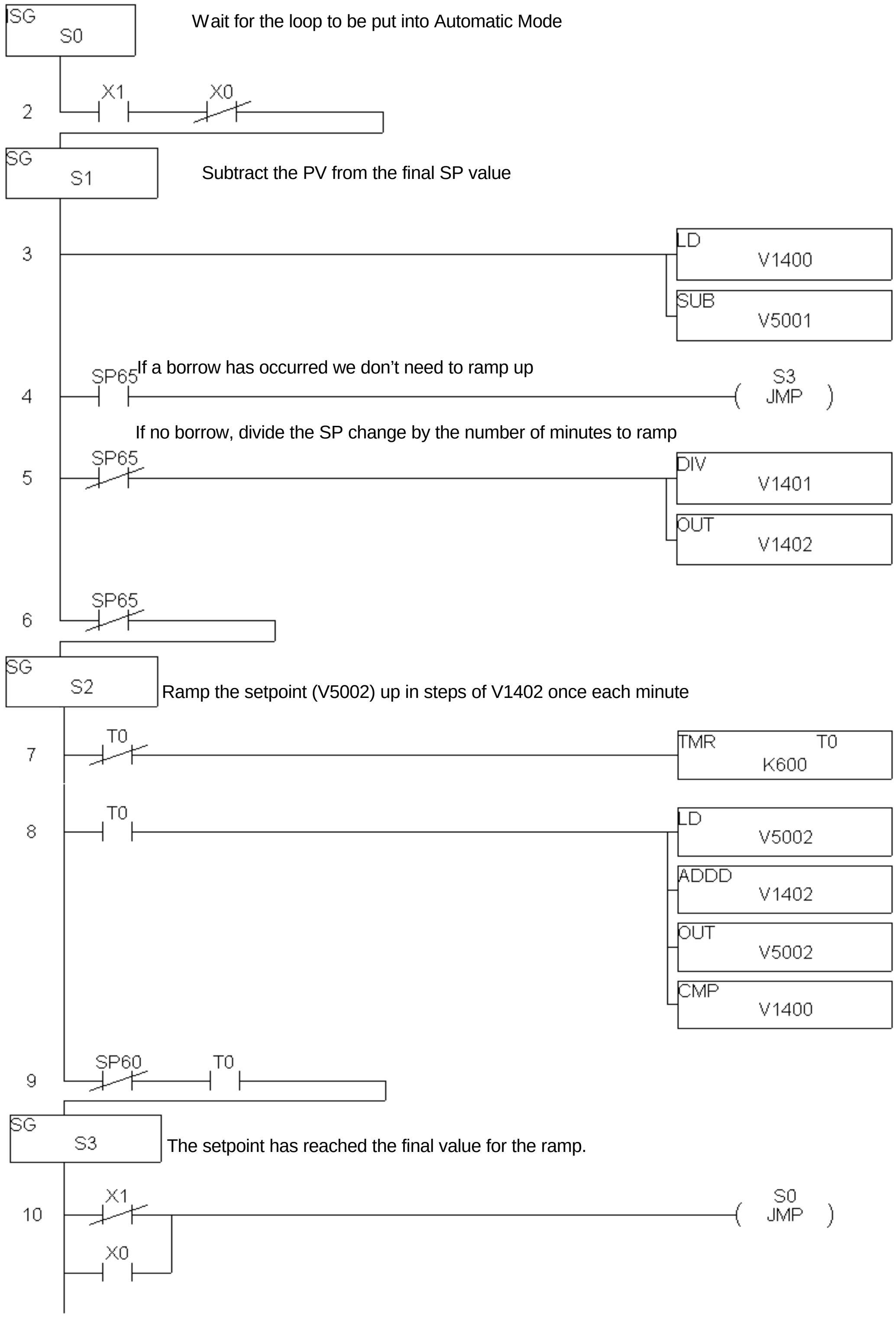
SETPOINT RAMP AND SOAK

For each loop the user can program a Ramp or Soak of the Setpoint as shown in the following examples.

Setpoint Ramp

A Ramp of the setpoint is the changing from the current Setpoint to a specified final Setpoint over a specified period of time.
In this example, the PV is used as the initial Setpoint. It is obtained from the PID parameter table for loop 1, V5001. The final Setpoint is in V1400 and the ramp time, in minutes, is stored in V1401. The loop should be configured so that the SP is automatically initialized to the PV when the loop is first but into Automatic mode.

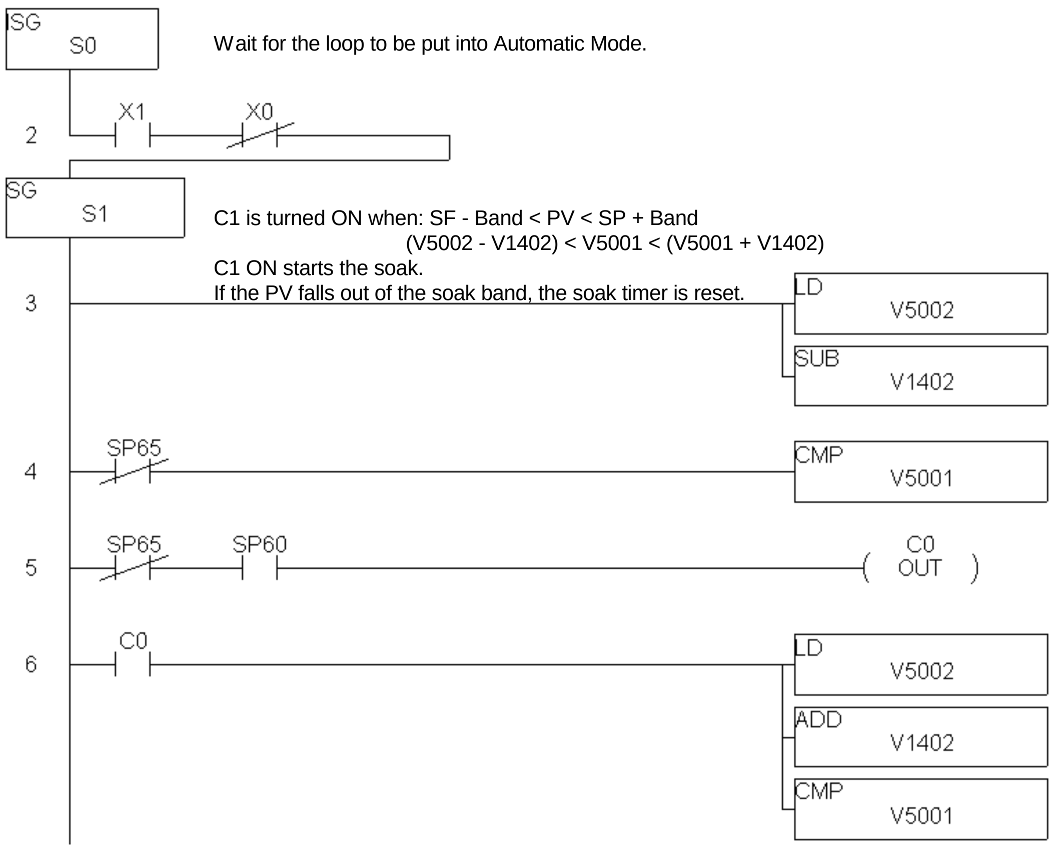
The holding time at each step is fixed at one minute. The size of the ramp step is calculated when the loop is first switched into Automatic mode, X1. The calculated ramp step is stored in V1402. The setpoint is increased from the initial PV value to the final Setpoint value. The example could easily be modified to ramp the Setpoint down to some lower final value.

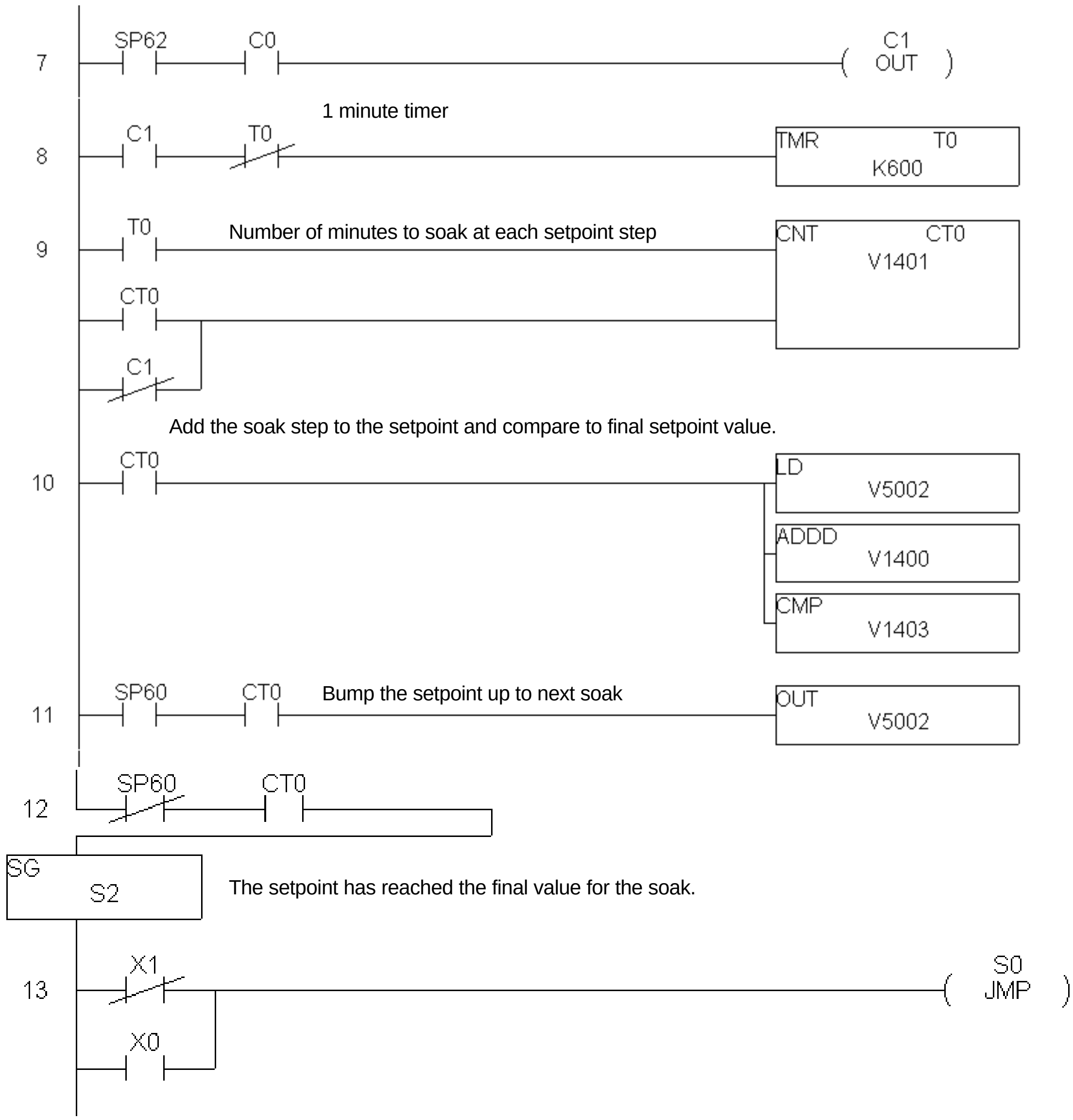


Setpoint Soak

A Soak of the setpoint is the changing from the current Setpoint to a specified final Setpoint in specified steps with each step maintained for a specified time. If guaranteed soaking is programmed, at each step change in the Setpoint, the Process Variable must be within a specified band around the Setpoint in order for the Soak time to be measured.

In this example, the step change in the Setpoint is stored in V1400. The Soak time, in minutes, is stored in V1401 and the PV band around the Setpoint is stored in V1402. The final Setpoint is stored in V1403.




7
SP62
C0
C1
OUT
1 minute timer
8
C1
T0
TMR
T0
K600
9
T0
Number of minutes to soak at each setpoint step
CNT
CT0
V1401
CT0
C1
Add the soak step to the setpoint and compare to final setpoint value.
10
CT0
LD
V5002
ADDD
V1400
CMP
V1403
11
SP60
CT0
Bump the setpoint up to next soak
OUT
V5002
12
SP60
CT0
SG
S2
The setpoint has reached the final value for the soak.
13
X1
S0
JMP
X0

TIME PROPORTIONING CONTROL LOOPS

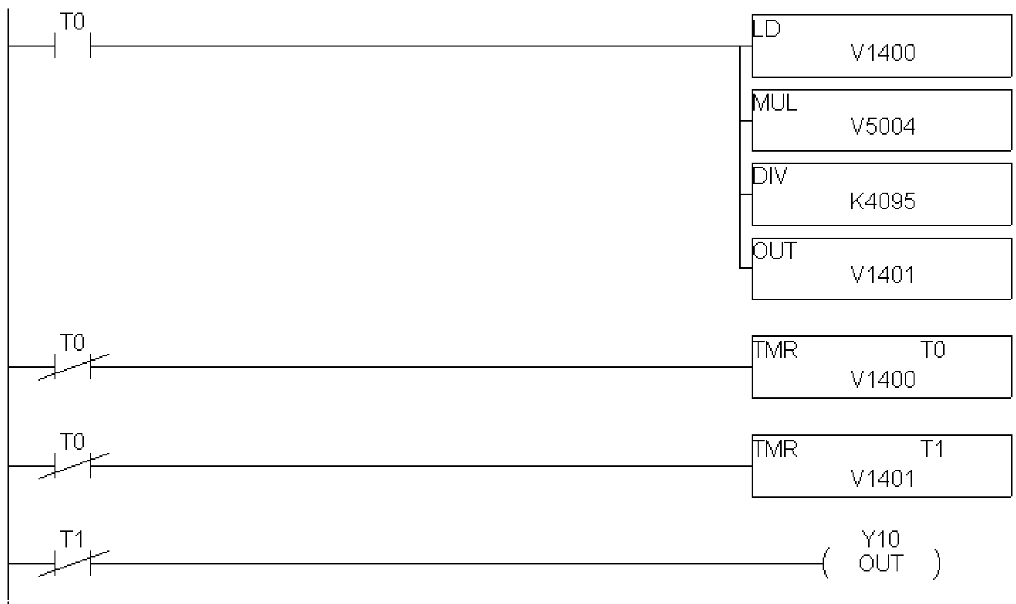
Time proportioning control permits a proportional PID output to be used with an ON/OFF device such as a discrete output connected to a heater element.

The following example implements time proportioning of an output, Y10.

The time proportioning cycle time (V1400 in this example) is the time the output would remain on for a loop output of 99.99%. The cycle time should be specified such that it is short compared to the dynamics of the process. Fast timers are used in the example for greater resolution, however, a normal timer could be used for a very slow process. In the example, a value of 1000 stored in V1400 would give a cycle time of 10 seconds.

The on time (V1401) is the cycle time multiplied by the percent of loop output.

V1401 = V1400 * V5004 (output of loop 1) / 4095

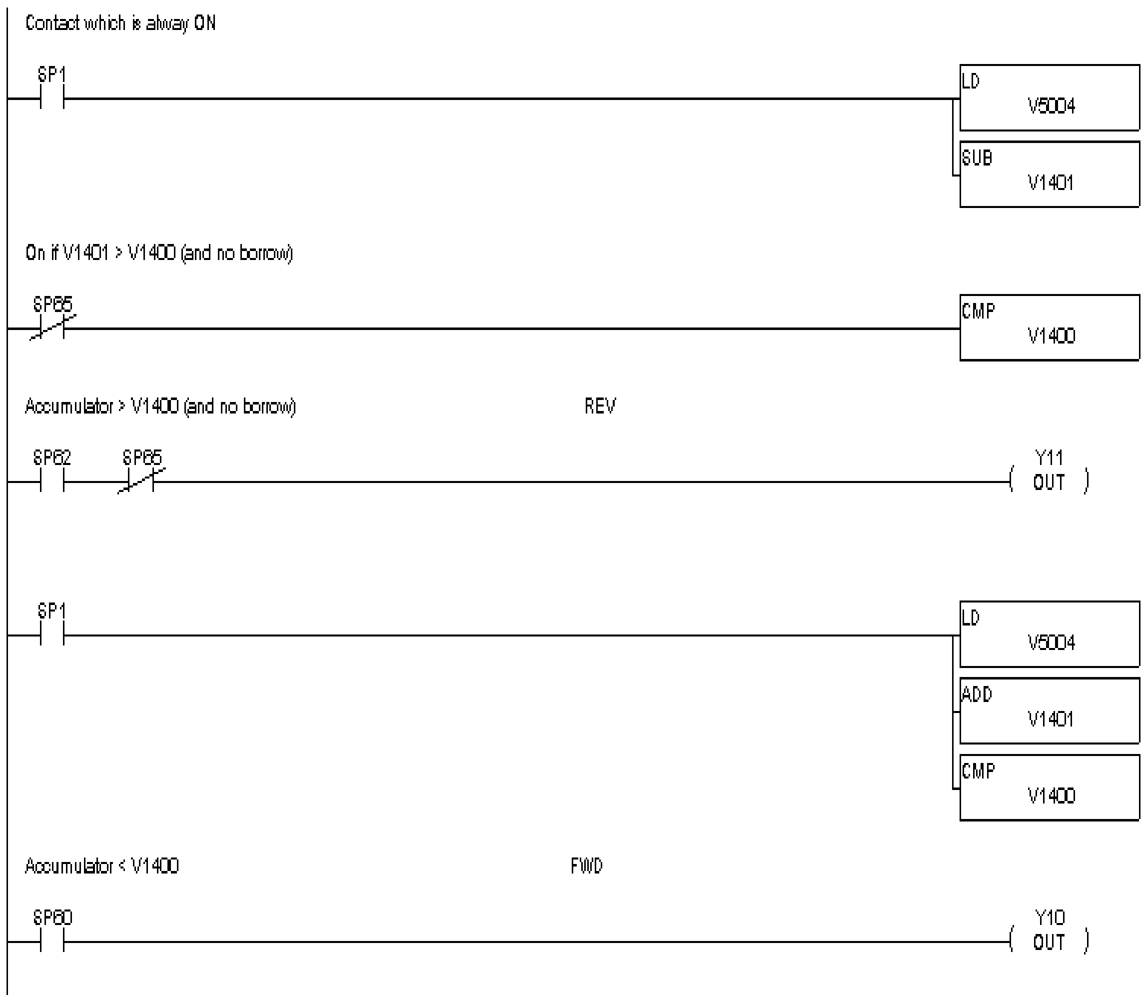


POSITIONING ACTUATOR CONTROL LOOPS

A reversible electric motor used to operate a valve is an example of a positioning actuator. This example will use the PID loop output in V5004 to position an actuator controlled by forward and reverse contacts. Y11 will run the motor in reverse and Y10 will turn the motor in the forward direction.

Feedback is required to correctly position the actuator. The actuator position could be input via a 4-20 mA signal derived from a slidewire connected to the actuator mechanism. A scaled BCD output of an absolute encoder connected to the motor might also be used to determine the actuator position. In this example, the actuator position is assumed to be in V1400. A value of 4095 (20 mA) in V1400 indicates that the actuator is 100% forward. A value of 0 (4 mA) in V1400 indicates that the actuator is at the reverse limit.

A tolerance is applied to the actuator position to prevent chattering of the outputs when the actuator is near the desired position. In this example, the deadband of the actuator positioning is specified in V1401.

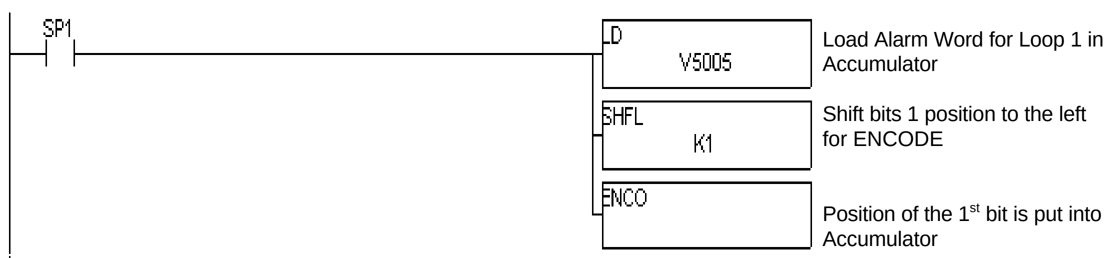


ENCODING THE ALARM WORD

Some operator interface software packages do not permit examining discrete bits in user V-Memory. The following example converts the bits in the Alarm Word into a corresponding BCD number.

If more than one alarm is on then the BCD number for the least significant bit in the Alarm Word will be returned. Thus a "Low Low PV Alarm" will override a "Low PV Alarm", a deviation and a rate-of-change alarm. A "Broken Transmitter Alarm" will always be recognized since in this case the PIDCOP disables all other alarms and loop processing.

Alarm Word		
Encoded BCD Number	Bit Number	Description
1	0	Low Low PV Alarm
2	1	Low PV Alarm
3	2	High High PV Alarm
4	3	High PV Alarm
5	4	PV Orange Deviation (Orange - Yellow)
6	5	PV Yellow Deviation
7	6	Rate of Change Alarm
8	7	Broken transmitter Alarm



CHAPTER 4: LOOP OPERATION

LOOP ALGORITHMS

Loop Variables

The input to 405 PID CoProcessor (PIDCOP) loops is called the Process Variable (PV). The result of the loop calculation is call the Output. Both the PV and Output are typically analog values and must be in the range 0-4095. PID Commander provides scaling of the PV to engineering units such as PSI.

When the PIDCOP reads the Process Variable for a loop, it will automatically convert it from a BCD number (0-4095) to a floating point number in the range of 0.0 to 1.0 (0.0 represents PV Low Range; 1.0 represents PV High Range). These values are referred to as normalized real numbers. All loop calculations are performed using normalized reals. The output from the loop is also a normalized real, which will be converted to a BCD number (0-4095) when stored to V-memory.

PID Control

The PIDCOP provides feedback loops using the PID (Proportional-Integral-Derivative) algorithm. The controller Output is computed from the measured process variable PV as follows:

Let

Kc = Proportional gain.
Ti = Reset or integral time.
Td = Derivative time or rate.
SP = Setpoint.
PV(t) = Process Variable at time "t".
e(t) = SP - PV(t) = PV deviation from Setpoint at time "t" or PV error

Then

M(t) = Controller output at time "t"

$$M(t) = Kc \left[e(t) + \frac{1}{Ti}\int_0^t e(x)\,dx + Td\frac{d}{dt}e(t) \right] + M_0$$

With the appropriate choice of Ti and Td values, the integral and derivative action may be eliminated resulting in the other common types of loops (P, PI, and PD).

Position Form of the PID equation

The PIDCOP approximates the output M(t) using a discrete position form of the PID equation.

Let

Ts = Sample rate.
Kc = Proportional gain.
Ki = Kc * (Ts / Ti) = Coefficient of the integral term
Kr = Kc * (Td / Ts) = Coefficient of the derivative term
Ti = Reset or integral time.
Td = Derivative time or rate.
SP = Setpoint.
PV_n = Process Variable at nth sample.
$e_n = SP - PV_n$ = Error at nth sample.
M_O = Value to which the controller output has been initialized

Then

M_n = Controller output at nth sample.

$$M_n = Kc * e_n + Ki \sum_{i=1}^{n} e_i + Kr\ (e_n - e_{n-1}) + M_0$$

This form of the PID equation is referred to as the position form since the actual actuator position is computed. The PIDCOP also provides a velocity form of the PID equation which computes the change in actuator position. The PIDCOP modifies the standard equation slightly to use the derivative of the Process Variable instead of the error as follows:

$$M_n = Kc * e_n + Ki \sum_{i=1}^{n} e_i + Kr\ (PV_n - PV_{n-1}) + M_0$$

These two forms are equivalent unless the setpoint is changed. In the original equation, a large step change in the setpoint will cause a correspondingly large change in the error resulting in a bump to the process due to derivative action. This bump is not present in the second form of the equation.

The PIDCOP also combines the integral sum and the initial output into a single term called the bias (Mx). This results in the following set of equations:

$Mx_0 = M_0$

$Mx = Ki * e_N + Mx_{n-1}$

$M_n = Kc * e_n - Kr\ (PV_n - PV_{n-1}) + Mx_n$

The PIDCOP by default will keep the normalized output M in the range 0.0 to 1.0. This is done by clamping M to the nearer of 0.0 or 1.0 whenever the calculated output falls outside this range. The PIDCOP also allows you to specify the minimum and maximum output clamp values (within the range 0 to 4095 in BCD).

Reset Windup Protection

Reset windup can occur if reset action (integral term) is specified and the computation of the bias term Mx is:

$$Mx = Ki * e_n + Mx_{n-1}$$

For example, assume the output is controlling a valve and the PV remains at some value greater than the Setpoint. The negative error (e_n) will cause the bias term (Mx) to constantly decrease until the output M goes to 0 closing the valve. However, since the error term is still negative, the bias will continue to decrease becoming ever more negative. When the PV finally does come back down below the SP, the valve will stay closed until the error is positive for long enough to cause the bias to become positive again. This will cause the controller to overshoot.

One way to solve the problem is to simply clamp the normalized bias between 0.0 and 1.0. The PIDCOP does this. However, if this is the only thing that is done then the output will not move off 0.0 (thus opening the valve) until the PV has become less than the SP. This will also cause the controller to undershoot.
The PIDCOP is programmed to solve the overshoot problem by either freezing the bias term, or by adjusting the bias term.

Freeze Bias

If the "Freeze Bias" option is selected when programming the PIDCOP then the PIDCOP simply stops changing the bias (Mx) whenever the computed normalized output (M) goes outside the interval 0.0 to 1.0.

$$Mx = Ki * e_n + Mx_{n-1}$$

$$M = Kc * e_n - Kr(PV_n - PV_{n-1}) + Mx$$

$$M_n = 0 \quad \text{if } M < 0$$
$$M_n = M \quad \text{if } 0 \le M \le 1$$
$$M_n = 1 \quad \text{if } M > 1$$

$$Mx_n = Mx \quad \text{if } 0 \le M \le 1$$
$$Mx_n = Mx_{n-1} \quad \text{otherwise}$$

Thus in our example, the bias will probably not go all the way to zero so that, when the PV does begin to come down, the loop will begin to open the valve sooner than it would have if the bias had been allowed to go all the way to zero. This action has the effect of reducing the amount of overshoot.

Adjusting the Bias

The normal action of the PIDCOP is to adjust the bias term when the output goes out of range as shown below.

$$Mx = Ki * e_n + Mx_{n-1}$$

$$M = Kc * e_n - Kr(PV_n - PV_{n-1}) + Mx$$

$$M_n = 0 \quad \text{if } M < 0$$
$$M_n = M \quad \text{if } 0 \le M \le 1$$
$$M_n = 1 \quad \text{if } M > 1$$

$$Mx_n = Mx \quad \text{if } 0 \le M \le 1$$
$$Mx_n = M_n - Kc * e_n - Kr(PV_n - PV_{n-1}) \quad \text{otherwise}$$

By adjusting the bias, the valve will begin to open as soon as the PV begins to come down. If the loop is properly tuned, overshoot can be eliminated entirely. If the output went out of range due to a setpoint change, then the loop probably will oscillate because we must wait for the bias term to stabilize again.

The choice of whether to use the default loop action or to freeze the bias is dependent on the application. **If large, step changes to the setpoint are anticipated, then it is probably better to select the freeze bias option.**

Step Bias Proportional to Step Change in SP

This option can be selected to reduce oscillation caused by a step change in setpoint when the adjusting the bias option is used.

$Mx = Mx * SP_n / SP_{n-1}$ if the loop is direct acting

$Mx = Mx * SP_{n-1} / SP_n$ if the loop is reverse acting

$Mx_n = 0$ if $Mx < 0$
$Mx_n = Mx$ if $0 \leq Mx \leq 1$
$Mx_n = 1$ if $Mx > 1$

Eliminating Proportional, Integral, or Derivative Action

Normally it is not necessary to run a full three mode PID control loop. Most loops require only the PI terms or just the P term. Parts of the PID equation may be eliminated by choosing appropriate values for the gain (Kc), reset (Ti), and rate (Td) yielding a P, PI, PD, I, and even an ID and a D loop.

Eliminating Integral Action The effect of integral action on the output may be eliminated by setting Ti = 9999. When this is done, the user may then manually control the bias term (Mx) to eliminate any steady-state offset.

Eliminating Derivative Action The effect of derivative action on the output may be eliminated by setting Td = 0.

Elimination Proportional Action Although rarely done, the effect of the proportional term on the output may be eliminated by setting Kc = 0. Since Kc is also normally a multiplier of the integral coefficient (Ki) and the derivative coefficient (Kr), the PIDCOP makes the computation of these values conditional on the value of Kc as follows:

$Ki = Kc * (Ts/Ti)$ if $Kc \neq 0$

$Ki = Ts/Ti$ if $Kc = 0$ (I or ID only)

$Kr = Kc * (Td/Ts)$ if $Kc \neq 0$

$Kr = Td/Ts$ if $Kc = 0$ (ID or D only)

Velocity Form of the PID Equation

The standard position form of the PID equation computes the actual actuator position. An alternative form of the PID equation computes the change in actuator position. This form of the equation is referred to as the velocity PID equation and is obtained by subtracting the equation at time "n" from the equation at time "n-1".

The velocity equation is given by:

$$\Delta M_n = M - M_{n-1}$$

$$\Delta M_n = Kc * (e_n - e_{n-1}) + Ki * e_n - Kr * (PV_n - 2 * PV_{n-1} + PV_{n-2})$$

Bumpless Transfer of Control

The PID CoProcessor provides for bumpless mode changes. A bumpless transfer from manual mode to automatic mode is achieved by preventing the controller output from changing immediately after the mode change.

When a loop is switched from Manual to Automatic mode, the Setpoint and Bias are initialized as follows:

Position PID Algorithm	Velocity PID Algorithm
SP = PV Mx = M	SP = PV

You can disable bumpless transfer of the Setpoint (3rd bit in mode word). This would be the same as using the Remote Setpoint option in the Series 505.

LOOP ALARMS

The PIDCOP allows the user to specify alarm conditions that are to be monitored for each loop. Alarm conditions are reported to the 405 CPU by the PIDCOP by setting bits in an "Alarm Word" located in the V-Memory parameter table. You may program a Y output or CR (control relay) to be activated based on an alarm condition. Please see the example on page 1.

PV Limit Specify up to four PV alarm points.

- **High-High** PV rises above the programmed High-High Alarm Limit.
- **High** PV rises above the programmed High Alarm Limit.
- **Low** PV falls below the Low Alarm Limit.
- **Low-Low** PV falls below the Low-Low Alarm Limit.

PV Deviation Specify an alarm for High and Low PV deviation from the setpoint (Yellow Deviation). An alarm for High High and Low Low PV deviation from the setpoint (Orange Deviation) may also be specified. When the PV is further from the Setpoint than the programmed Yellow or Orange Deviation Limit corresponding alarm bit is activated.

Rate-of-Change This alarm is set when the PV changes faster than a specified rate-of-change limit.

Broken Xmitter This alarm is set when the PV is less than 2.4 mA. It is effective when a 4-20 mA transmitter is used with a 0-20 mA analog input range and the 20% offset of PV operation is selected.

Deadband Specify .1% to 5% alarm deadband on all alarms except Rate-of-Change. The loop will not exit the alarm condition until the PV has come inside the alarm limit minus the deadband. Alarm deadband prevents alarm chatter.

LOOP OPERATING MODES

The PIDCOP operates in one of two modes, either Manual or Automatic.

Manual

In Manual mode, the loop output is determined by the operator, not the PIDCOP. While in manual mode, the PID CoProcessor will still monitor all of the alarms including Broken Transmitter, High-High, High, Low, Low-Low, Yellow deviation , Orange deviation and Rate-of-Change.

Automatic

In Automatic mode, the PIDCOP computes the loop output based on the programmed parameters stored in V-Memory. All alarms are monitored while in automatic.

Cascade

Loops may be cascaded using minimal additional ladder logic as described on page 11.

SPECIAL LOOP CALCULATIONS

Reverse Acting Loop

The PIDCOP allows a loop to be programmed as reverse acting. With a reverse acting loop, the output is driven in the opposite direction of the error. For example, if SP>PV then a reverse acting controller will decrease output to increase the PV.

$$Mx = -Ki * e_n + Mx_{n-1}$$

$$M = -Kc * e_n + Kr(PV_n - PV_{n-1}) + Mx$$

Square Root of the Process Variable

Select square root if the PV is from a device such as an orifice meter which requires this calculation.

Error Squared Control

When error squared control is selected, the error is calculated as:

$e_n = (SP - PV_n) * ABS(SP - PV_n)$

A loop using the error squared is less responsive than a loop using just the error. The smaller the error, the less responsive the loop. Error squared control would typically be used in a PH control application.

Error Deadband Control

With error deadband control, no control action is taken if the PV is within the specified deadband area around the setpoint. The error deadband need not be the same above (e.g. V5023) and below (e.g. V5022) the setpoint.

Once the PV is outside of the error deadband around the Setpoint, the entire error is used in the loop calculation.

$e_n = 0$ SP - Deadband_Below_SP < PV < SP - Deadband_Above_SP
$e_n = SP - PV_n$ otherwise

The error will be squared first if both Error Squared and Error Deadband Control is selected.

Derivative Gain Limiting

When the coefficient of the derivative term, Kr, is a large value, noise introduced into the PV can result in erratic loop output. This problem is corrected by specifying a derivative gain limiting coefficient, Kd. Derivative gain limiting is a first order filter applied to the derivative term computation, Y_n, as shown below.

$$Y_n = Y_{n-1} + \frac{Ts}{TS + (\frac{Td}{Kd})} * (PV_n - Y_{n-1})$$

Position Algorithm

$Mx = Ki * e_n + Mx_{n-1}$

$M = Kc * e_n - Kr * (Y_n - Y_{n-1}) + Mx$

Velocity Algorithm

$\Delta M = Kc * (e_n - e_{n-1}) + Ki * e_n - Kr * (Y_n - 2 * Y_{n-1} + Y_{n-2})$

SPECIAL FUNCTION PROGRAMMING

Using a BASIC CoProcessor, ladder logic, or Machine Stage, the user may perform additional computations on the SP, PV, Output or other loop parameters and variables.

Typical special function programming examples are:
- Computations on the Process variable such as filtering.
- Computations on the Setpoint for a ratio-control application.
- Computations on the loop Output before it is written to an analog output module.

APPENDIX A: V-MEMORY MAP

There can be up to 5 PIDCOPs per base. Each PIDCOP has three dedicated V-Memory locations associated with it to specify the starting address of the loop parameters table, the number of PID loops enabled (scanned) for that module, and a location for the module to return configuration error codes.

DEDICATED V-MEMORY MAP

The dedicated V-Memory locations are only read by the PIDCOP at power-up or when the PLC mode is switched from program to run.

Each PID loop parameter table is 32 V-Memory locations long. The number of loops enabled controls the size of the block of V-Memory used by each PIDCOP. The beginning address of the PIDCOP's loop parameter table is specified by a V-Memory pointer stored in the modules Table Beginning Address location (see below). Normally the Table Beginning Address will be in retentive V-Memory, V2000 - V7377.

The dedicated V-Memory Error Code location for each PIDCOP contains a configuration error code plus firmware revision level.

High Byte = Version Number

Low Byte = Configuration Error Codes

0 = Valid configuration
1 = Starting table address below user v-memory
2 = Starting table address too high
3 = More than 16 loops enabled
4 = Starting address is too low for number of loops

Example: A BCD Error Code of 1002 indicates the starting table address is too high and the PIDCOP firmware version is 1.0.

PIDCOP Configuration Memory Map			
Slot Number	Table Beginning Address	Number of Loops Enabled	Error Code
0	V7350	V7351	V7352
1	V7353	V7354	V7355
2	V7356	V7357	V7360
3	V7361	V7362	V7363
4	V7364	V7365	V7366
5	V7367	V7370	V7371
6	V7372	V7373	V7374
7	V7375	V7376	V7377

Example: To specify V5000 as the loop parameter table beginning address for a PIDCOP in slot 4, V7364 would contain the BCD number 5000. To enable all 16 loops for this module, V7365 would contain the BCD number 16. Thus the module will use all V-Memory locations from V5000 to V5777.

PID Parameter Loop Table Memory Map			
Decimal Offset	Example V - Memory	Description	PIDCOP Usage
0	V5000	Mode Word (bit mapped)	0 - 2 Read Continually
1	V5001	PV (Process Variable)	
2	V5002	SP (SetPoint)	
3	V5003	Bias	Write (Read if Proportional Control Only)
4	V5004	Output (0 - 4095)	4 - 5 Write after each loop update
5	V5005	Alarm Word (bit mapped)	
6	V5006	Sample Rate (nnn.d)	6 -31 Read if Mode Word bit 15 is set
7	V5007	Gain (nn.dd) (P)	
8	V5010	Reset (nnn.d min., sec, msec, usec) (I)	(default in Min.)
9	V5011	Rate (nn.dd) (D)	
10	V5012	PV Low Low Alarm	(Note 1)
11	V5013	PV Low Alarm	(Note 1)
12	V5014	PV High High Alarm	(Note 1)
13	V5015	PV High Alarm	(Note 1)
14	V5016	PV Yellow Deviation Limit	(Note 1)
15	V5017	PV Orange Deviation Limit	(Orange > Yellow) (Note 1)
16	V5020	PV Rate of Change Limit	(Note 1)
17	V5021	Alarm Deadband (Range 0.1 - 5.0%)	
18	V5022	Error Deadband Below SP	(Note 1)
19	V5023	Error Deadband Above SP	(Note 1)
20	V5024	Derivative Gain Limiting Coefficient	
21	V5025	SetPoint Low Limit	(Note 1)
22	V5026	SetPoint High Limit	(Note 1)
23	V5027	Maximum Output Clamp	
24	V5030	Minimum Output Clamp	
25	V5031	Extended Mode Word (bit mapped)	
26	V5032	Reserved for Future use	
27	V5033	Reserved for Future use	
28	V5034	Reserved for Future use	
29	V5035	Reserved for Future use	
30	V5036	Reserved for Future use	
31	V5037	Reserved for Future use	

Note 1: Range is 0 - 4095. If 20% offset is selected in Extended Mode Word then Range is 819 - 4095. All values except bit mapped words are in BCD.

Bit Mapped Registers - Mode Word		
Hexadecimal Weight	Bit Number	Description
1	0	1 = Manual Mode (Overrides Automatic)
2	1	1 = Automatic Mode
4	2	1 = Disable Bumpless Transfer of SP, 0 = Manual - Automatic SP = PV
8	3	1 = Reverse Acting, 0 = Direct Acting
10	4	0 = Position, 1 = Velocity PID Alogorithm
20	5	1 = Square Root of PV
40	6	1 = High / Low Error Deadband Operation
80	7	1 = Error Squared
100	8	1 = Sample Rate and Derivative Time units = Minutes 0 = Seconds
200	9	1 = Derivative Gain Limiting
400	10	1 = Freeze Bias when Output goes out of range
800	11	1 = Step Bias Proportional to Step change in SP
1000	12	1 = Monitor PV for Low Low / High High and Low / High Limits
2000	13	1 = Monitor PV Deviation
4000	14	1 = Monitor PV Rate of Change
8000	15	1 = Set by user so PIDCOP will read fixed loop data 0 = PIDCOP clears after fixed loop data is read

The Extended Mode Word is at V - Memory offset address 25 decimal. This is V5031 in the example.

Extended Mode Word (V5031)		
Hexadecimal Weight	Bit Number	Description
1	0	1 = 20% offset of PV for input of 4 - 20 mA on 0 - 20mA range
2	1	1 = Monitor Broken Transmitter - Alarm set if PV < 2.4mA
4	2	1 = Reset units is seconds, nnn.d (See Note: 1)
8	3	1 = Reset units is milliseconds, nnn.d (See Note: 1)
10	4	1 = Reset units is microseconds, nnn.d (See Note: 1)
20	5	Reserved for future feature enhancements
40	6	Reserved for future feature enhancements
80	7	Reserved for future feature enhancements
100	8	Reserved for future feature enhancements
200	9	Reserved for future feature enhancements
400	10	Reserved for future feature enhancements
800	11	Reserved for future feature enhancements
1000	12	Reserved for future feature enhancements
2000	13	Reserved for future feature enhancements
4000	14	Reserved for future feature enhancements
8000	15	Reserved for future feature enhancements

Note: 1 - reset units is minutes, nnn.d , if bits 2,3and 4 are off. If more than one of these bits is on, then the smallest unit selected is activated.

The Alarm Word is at V-Memory offset address 5 decimal. This is V5005 in the example.

Alarm Word		
Hexadecimal Weight	Bit Number	Description
1	0	1 = Low Low PV Alarm
2	1	1 = Low PV Alarm
4	2	1 = High High PV Alarm
8	3	1 = High Alarm
10	4	1 = PV Orange Deviation (Orange > Yellow)
20	5	1 = PV Yellow Deviation
40	6	1 = Rate-of-Change Alarm
80	7	1 = Broken Transmitter Alarm
100	8	1 = Reserved for future feature enhancements
200	9	1 = Reserved for future feature enhancements
400	10	1 = Reserved for future feature enhancements
800	11	1 = Reserved for future feature enhancements
1000	12	1 = Reserved for future feature enhancements
2000	13	1 = Reserved for future feature enhancements
4000	14	1 = Reserved for future feature enhancements
8000	15	Watch-Dog Bit, Toggles every loop update

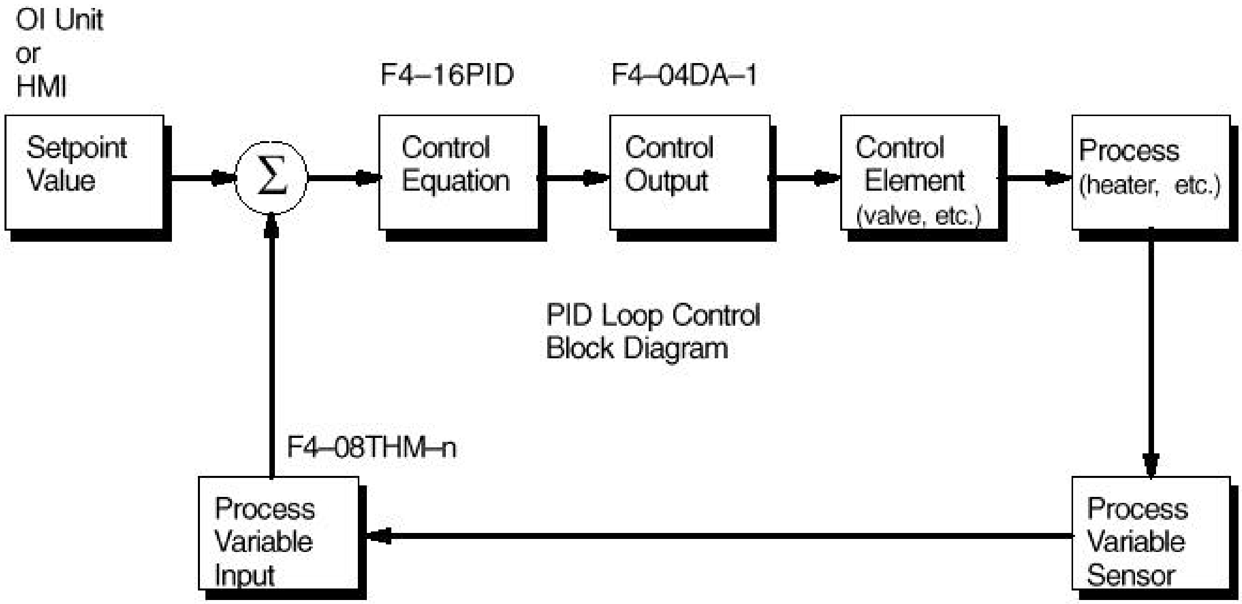
PID LOOP TABLE V-MEMORY MAP

Any V-Memory address may be specified as the loop table starting address for a given module. Normally retentive V-Memory is used to store loop parameters (V2000-V7377). The following V-Memory map shows the addressing for the maximum number of PIDCOPs permitted in a single 405 system (5 PIDCOPs, 80 loops with 256 non-retentive and 232 retentive V-Memory locations unused).

1st PIDCOP		2ND PIDCOP		3rd PIDCOP		4th PIDCOP		5th PIDCOP	
V-Memory Address of Mode Word	PID Loop Number	V-Memory Address of Mode Word	PID Loop Number	V-Memory Address of Mode Word	PID Loop Number	V-Memory Address of Mode Word	PID Loop Number	V-Memory Address of Mode Word	PID Loop Number
V2000	1	V3000	1	V4000	1	V5000	1	V6000	1
V2040	2	V3040	2	V4040	2	V5040	2	V6040	2
V2100	3	V3100	3	V4100	3	V5100	3	V6100	3
V2140	4	V3140	4	V4140	4	V5140	4	V6140	4
V2200	5	V3200	5	V4200	5	V5200	5	V6200	5
V2240	6	V3240	6	V4240	6	V5240	6	V6240	6
V2300	7	V3300	7	V4300	7	V5300	7	V6300	7
V2340	8	V3340	8	V4340	8	V5340	8	V6340	8
V2400	9	V3400	9	V4400	9	V5400	9	V6400	9
V2440	10	V3440	10	V4440	10	V5440	10	V6440	10
V2500	11	V3500	11	V4500	11	V5500	11	V6500	11
V2540	12	V3540	12	V4540	12	V5540	12	V6540	12
V2600	13	V3600	13	V4600	13	V5600	13	V6600	13
V2640	14	V3640	14	V4640	14	V5640	14	V6640	14
V2700	15	V3700	15	V4700	15	V5700	15	V6700	15
V2740	16	V3740	16	V4740	16	V5740	16	V6740	16

APPENDIX B: Application Example - 4 Loops

This application example describes hardware and ladder logic programming for a typical 4 loop PID control using the F4-16PID coprocessor.



I/O Listing	
Symbol	Description
X0	Loop 1 Manual Mode
X1	Loop 1 Automatic Mode
X2	Loop 2 Manual Mode
X3	Loop 2 Automatic Mode
X4	Loop 3 Manual Mode
X5	Loop 3 Automatic Mode
X6	Loop 4 Manual Mode
X7	Loop 4 Automatic Mode
X10-X17	Spare
X20-X33	12 bit Data from Analog Input Module
X34-X37	Analog Input module channel Identification
Y0-Y13	12 bit Data for Analog output module
Y14-Y17	Analog output module channel select
Y20	Loop1 Low Low PV Alarm
Y21	Low PV Alarm
Y22	High High PV Alarm
Y23	High PV Alarm
Y24	PV Orange Deviation

Y25	PV Yellow Deviation
Y26	Rate of Change Alarm
Y27	Broken Transmitter Alarm
Y30	Loop2 Low Low PV Alarm
Y31	Low PV Alarm
Y32	High High PV Alarm
Y33	High PV Alarm
Y34	PV Orange Deviation
Y35	PV Yellow Deviation
Y36	Rate of Change Alarm
Y37	Broken Transmitter Alarm
Y40	Loop3 Low Low PV Alarm
Y41	Low PV Alarm
Y42	High High PV Alarm
Y43	High PV Alarm
Y44	PV Orange Deviation
Y45	PV Yellow Deviation
Y46	Rate of Change Alarm
Y47	Broken Transmitter Alarm
Y50	Loop4 Low Low PV Alarm
Y51	Low PV Alarm
Y52	High High PV Alarm
Y53	High PV Alarm
Y54	PV Orange Deviation
Y55	PV Yellow Deviation
Y56	Rate of Change Alarm
Y57	Broken Transmitter Alarm

Ladder Logic

Loop 1 Mode control and alarming

Load bit Mask

Load all Mode bits
except Auto/Man.

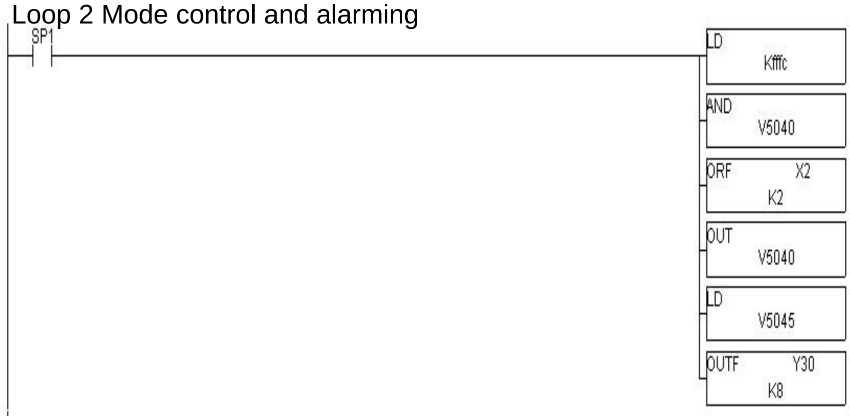
Add the Auto/Man. Inputs
to mode control

Put back the loop1 mode control word

Get the alarm word to the accumulator

Write the 8 alarm bits to the
annunciators

Loop 2 Mode control and alarming



Load bit mask

Load all mode bits
except Auto/Man.

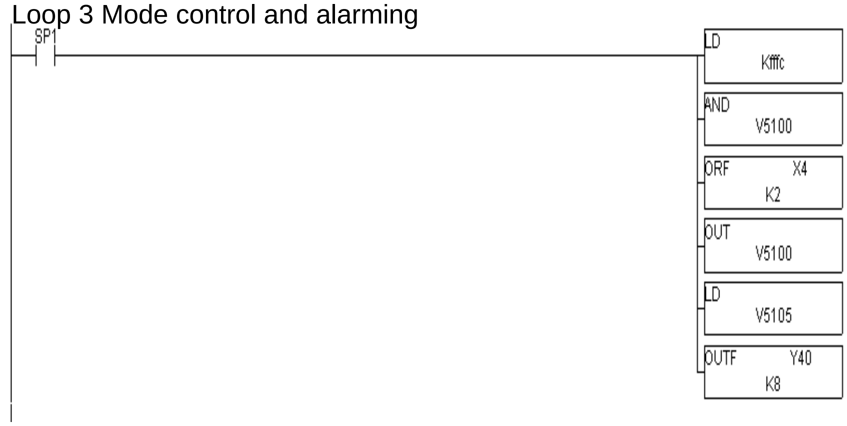
Add the Auto/Man. Inputs
to mode control

Put back the loop2 mode control word

Get the alarm word to the accumulator

Write the 8 alarm bits to the
annunciators

Loop 3 Mode control and alarming



Load bit mask

Load all mode bits
except Auto/Man.

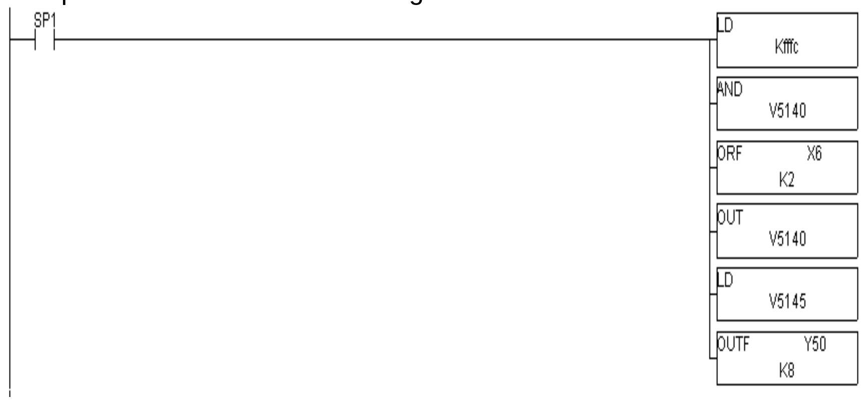
Add the Auto/Man. Inputs
to the mode control

Put back the loop 3 mode control word

Get the alarm word to the accumulator

Write the 8 alarm bits to the
annunciators

Loop 4 Mode control and alarming



Load bit mask

Load all mode bits
except Auto/Man.

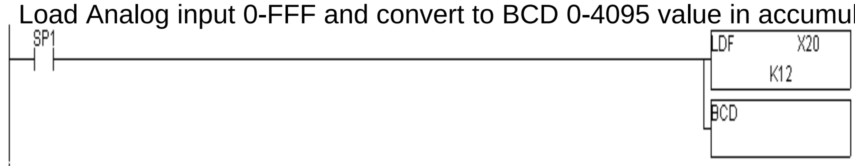
Add the Auto/Man. Inputs
to the mode control

Put back the loop 3 mode control word

Get the alarm word to the accumulator

Write the 8 alarm bits to the
annunciators

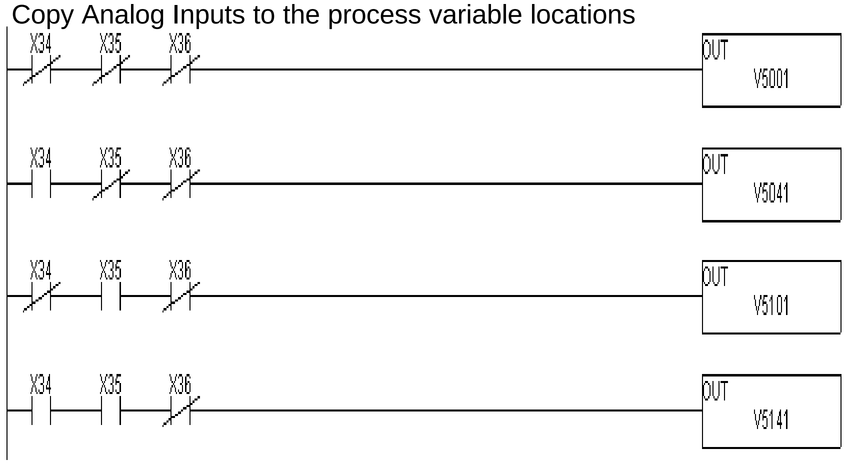
Load Analog input 0-FFF and convert to BCD 0-4095 value in accumulator



Move 12 bits of data into accumulator

Convert binary value in accumulator to
BCD

Copy Analog Inputs to the process variable locations



Process Variable Loop 1

Process Variable Loop 2

Process Variable Loop 3

Process Variable Loop 4

Copy Analog inputs to the Process Variable location

Copy loop outputs to the analog outputs which control the process