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Direct Logic 405

Four Loop Temperature Controller

F4-4LTC

Manual Order Number: F4-4LTC-M

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CHAPTER 1: INTRODUCTION

GENERAL DESCRIPTION

The Direct Logic 405 Four Loop Temperature Controller CoProcessor integrates into one single slot module, all the functions of four, single loop temperature controllers. Because the module uses the DL405 high speed parallel dual port RAM interface, the effect on CPU scan time is minimal.

TEMPERATURE CONTROL

The module provides control outputs and temperature inputs so that precision temperature control is maintained even while the PLC is in program mode.

Auto tuning of the Controller PID loops provides simple setup and maintenance. Auto tuning easily adapts to changing process conditions. Because the floating point math intensive temperature calculations are performed in the Controller, it has little effect on CPU scan time. In most applications, no supporting ladder logic is required.

The power of the DL405 can be used to enable features beyond the capabilities of most single loop temperature controllers. For example, minimal additional ladder logic is needed to ramp and soak SetPoint changes or to change process recipes.

CONTROLLER I/O

The Controller is jumper selectable for direct connection to either RTD or Thermocouple temperature sensors.

On board solid state outputs are used to cycle heater or cooler relays using either time proportioning (pulse) PID or ON/OFF control logic. The controller output is also placed in the PLC for optional use with DL405 4-20 mA or voltage linear analog output modules.

A current transformer is connected directly to the Temperature Controller to provide heater burn-out detection.

User field wiring is made to a removable socket type terminal block on the controller's face plate. Thus the temperature controller can be easily removed or changed without removing the field wiring.

OPERATOR INTERFACE

All Temperature Controller parameters are placed in V-Memory so that configuration, operation and monitoring are easily adapted to the needs of every application. Temperature values are in engineering units, either °C or °F.

Users	An intelligent Operator Interface Terminal or industrial computer connected to either port on a DL405 CPU can be used to change SetPoints and monitor operation. A single OIT can service one or several DL405 systems using the 25 pin DirectNET network port on 405 CPU.
OEMs	The temperature SetPoint in V-Memory may be easily changed via a Hand Held Programmer or an attached operator interface.

ALARMING AND DIAGNOSTICS

LEDs

The 20 LEDs on the face of the module provide a quick indication of the operating status of all four temperature loops. An LED is provided for each loop to indicate when an Output is ON, Auto Tune is ON, an Alarm condition is present or when heater burn-out has been detected. In addition, there are Missing Terminal Block (TB), No External Power (24V), RUN, and OK LED indicators.

Alarms

The Temperature Controller alarms include, Low Alarm, High Alarm, Deviation Alarm, No Heater Current Alarm (heater burn-out), Shorted Heater Output and Broken RTD or Thermocouple Alarm.

Low Level Diagnostics

The module performs both high and low level self diagnostics. Possible low level diagnostic errors include, CPU Error, Firmware Error (Watchdog time-out circuit), Incorrect ROM Checksum, RAM Error, and Analog Circuit Error. These errors are reported to PLC CPU in a slot dependent V-Memory location.

High Level Diagnostics

High level diagnostics include Loose Terminal Block and External Power Supply Failure diagnostic errors. These errors are reported to the PLC CPU and identified on the module by LED indicators.

Loose Terminal Block and External Power Supply Failure diagnostic errors are reported to the DL405 CPU. An operator may use AUX 42 to determine the error type. Either error will also turn ON special purpose coil SP45. V-Memory location V7762 will contain 0201 if the terminal block is loose. V7762 will contain 0206 if no external power supply is present. V7760 specifies the base and module of the error (0102 = Base 1 module 2).

OPERATIONAL SPECIFICATIONS

Installation	Up to 8 Temperature Controllers may be used with a single 405 CPU. Temperature Controllers must be installed in the CPU base.
V-Memory Block	A slot dependent V-Memory location specifies the starting address of the block of V-Memory to be used by the Temperature Controller.
Loops	Up to 4 independent temperature loops can be controlled. A unique V-Memory location specifies the number of loops which are enabled for each Temperature Controller.
Algorithm	PID control with auto tuning or ON/OFF control with hysteresis.
Limit SP	Optionally, specify a high and low limit for allowable SetPoint changes.
Scaling	Conversion of the temperature value to engineering units is automatically done by the Controller.
Gain	Specify proportional gain of 0.0 to 6553.5. Gain may be determined automatically by using the Auto Tuning feature.
Reset	Specify reset time of 0 to 65535 seconds. Reset may be determined automatically by using the Auto Tuning feature.
Anti-windup	The reset action is stopped when the PID output reaches 0 or 100%.
Rate	Specify the derivative time, 0 to 65535 in units of seconds. Rate may be determined automatically by using the Auto Tuning feature.
Auto Tune	Auto Tune can be programmed to calculate either PID or PI controller settings.

ALARM SPECIFICATIONS

Deadband	Specify the temperature deadband on all alarms. The alarm will remain active while the temperature is outside the alarm limit minus the deadband. Alarm deadband prevents alarm chatter when the temperature is near the alarm limit.
Temperature High	The Temperature High Alarm is turned on when the temperature rises above the programmed limit.
Temperature Low	The Temperature Low Alarm is turned on when temperature falls below the programmed limit.
Deviation	Specify an alarm for high or low temperature deviation from the SetPoint. When the temperature is further from the SetPoint than the programmed deviation limit the Temperature Deviation Limit Alarm is turned on.
Broken Sensor	The Broken RTD or Thermocouple alarm is turned on when the a RTD or Thermocouple is burned-out or missing. It also is turned on when a RTD input is shorted. In both cases the indicated temperature will be full scale positive, 3276.7 °C or °F.

TEMPERATURE CONTROLLER HARDWARE SPECIFICATIONS

General Specifications	
Number of Loops	4
Input Type	Differential
Common Mode Range	± 5 Vdc
Converter Type	Charge Balancing, 24-bit
Controller Output	Open collector, 5 to 50 Vdc at .15A.
Notch Filter	> 100 db notches at 50 Hz and 60 Hz f-3db = 13.1 Hz
Common-Mode Rejection	90 db minimum at DC 150 db minimum at 50 Hz and 60 Hz
Sampling Rate	800 msec per loop (Slow 10 Hz Filter) 160 msec per loop (Normal 50 Hz Filter)
Current Transformer	5 A to 50 A sense range F4-CT or equal (The F4-CT Current Transformer input to output current ratio is approximately 400:1)
Minimum Output ON time	300 msec to sense heater current
Mounting	Single slot in CPU base, up to eight modules per system
I/O Points Required	None, uses high speed intelligent parallel dual port memory interface
LED Status Indicators	20
User Wiring	Removable Terminal Block
Input Type Combinations	J,K,E,N or R,S,B,C or T or Pt100,jPt100 or Pt1000 or CU-10Ω or CU-25Ω.

Environmental Specifications	
Operating Temperature	0 °C to 60 °C (32 °F to 140 °F)
Relative Humidity	5 to 95% (non-condensing)
Storage Temperature	-20 °C to 70 °C (-4 °F to 160 °F)
Internal Power Required	280 mA at +5 V dc Maximum from base power supply
External Power Required	75 mA at 24 V dc, ± 10%
Power Supply Rejection	85 db typical

Voltage Input Specifications	
Voltage Ranges	0-5, ±5V, 0-156.25, ±156.25mV
Resolution	16-bit binary (1 in 65536)
Calibration Error	±13 counts typ., ±33 maximum full scale ±1 count maximum offset (0V input)
Maximum Inaccuracy	±.02% typ. ±.2% maximum

Thermocouple Input Specifications	
Temperature Ranges	Type J -190/760 °C (-310/1400 °F) Type E -210/1000 °C (-346/1832 °F) Type K -150/1372 °C (-238/2502 °F) Type R +65/1768 °C (+149/3214 °F) Type S +65/1768 °C (+149/3214 °F) Type T -230/400 °C (-382/752 °F) Type B 529/1820 °C (+984/3308 °F) Type N -70/1300 °C (-94/2372 °F) Type C +65/2320 °C (+149/4208 °F)
Input Fault Protection	60 Vrms or 50 Vdc maximum
Cold Junction Compensation	Automatic
Input Impedance	20 MΩ
Resolution	±0.1 °C (Relative accuracy)
Warm-Up Time	30 min. typ. for ±1 °C repeatability
Maximum Inaccuracy	±3 °C excluding error of thermocouple (See page 2.7 for additional sources of inaccuracy)

RTD Input Specifications	
RTD Types	European, = .003850, (Pt100 & Pt1000) American, = .003916, (jPt100) Copper (CU-10Ω & CU-25Ω)
Temperature Ranges	Pt100, -200.0/850.0 °C (-328/1562 °F) Pt1000, -200.0/595.0 °C (-328/1103 °F) jPt100, -38.0/450.0 °C (-36/842 °F) CU-10/25Ω, -200.0/260.0 °C (-328/500 °F)
Input Fault Protection	50 Vdc maximum
RTD Excitation Current	200 µA
Resolution	±0.1 °C or °F
Maximum Inaccuracy	±1 °C

CHAPTER 2: INSTALLATION AND WIRING

STEPS FOR F4-4LTC INSTALLATION

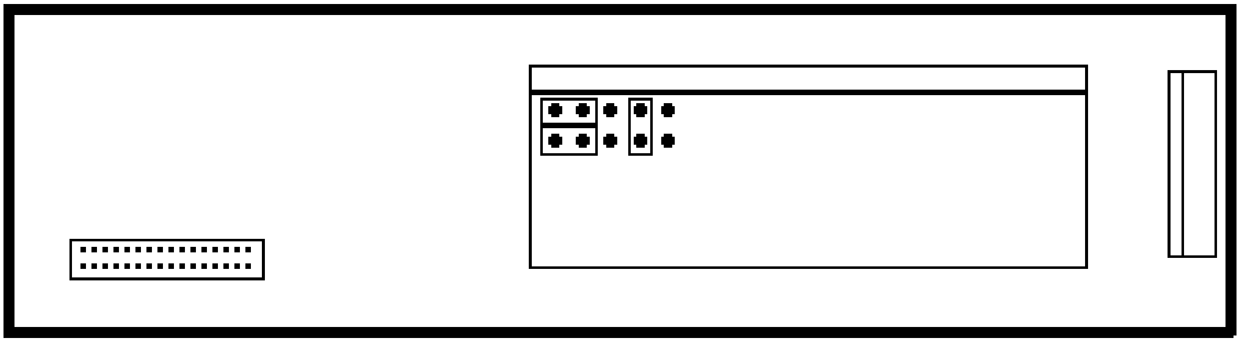
The following steps should be used as guideline for installation of the F4-4LTC. All steps may not be necessary in all applications.

1. Set Jumpers for RTD or Thermocouple
2. Install F4-4LTC in the CPU Base and Note the Slot Number
3. Connect Temperature Sensors to TEMP Inputs
4. Connect SSR Controller Outputs to SSRs
5. Connect CT Inputs to Current Transformers
6. Connect 24VDC Power Supply to F4-4LTC
7. Power Up PLC and Initialize Dedicated V-Memory
8. Initialize Loop Configuration V-Memory
9. Tune Loops

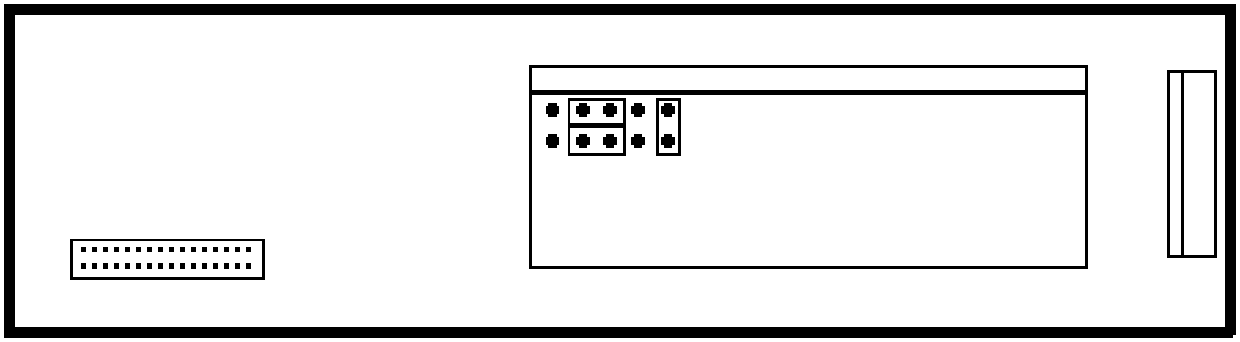
SET CONFIGURATION JUMPERS

The module should be jumpered for the type of input device that it will be connected to. Use the following diagrams to configure the jumpers on your module. The two configurations shown here are the only valid settings, any other settings may cause unpredictable results.

RTD Inputs



Voltage or Thermocouple Inputs



UNUSED TEMPERATURE INPUTS

Unused temperature inputs should be shorted together and connected to 24V common. For example, if only three temperature loops are required, then wire the TEMP 4 +, TEMP 4 -, and COM terminal block positions together

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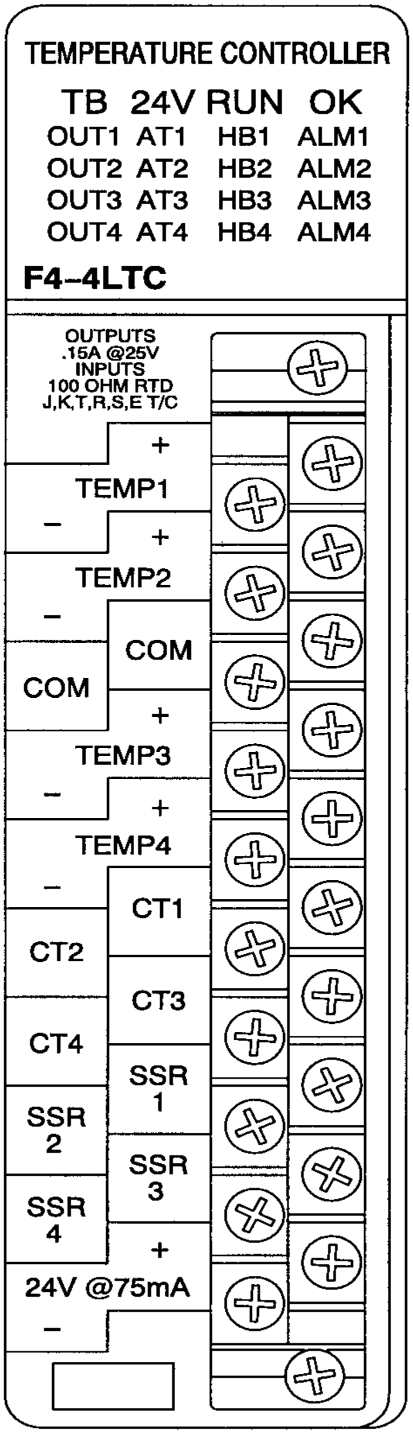
WARNING **A thermocouple or RTD temperature sensor can become shorted to a high voltage potential. Because common terminals are internally connected together on the F4-4LTC, whatever voltage potential exists on one temperature sensor will exist on the other three.**

INSTALL F4-4LTC IN CPU BASE

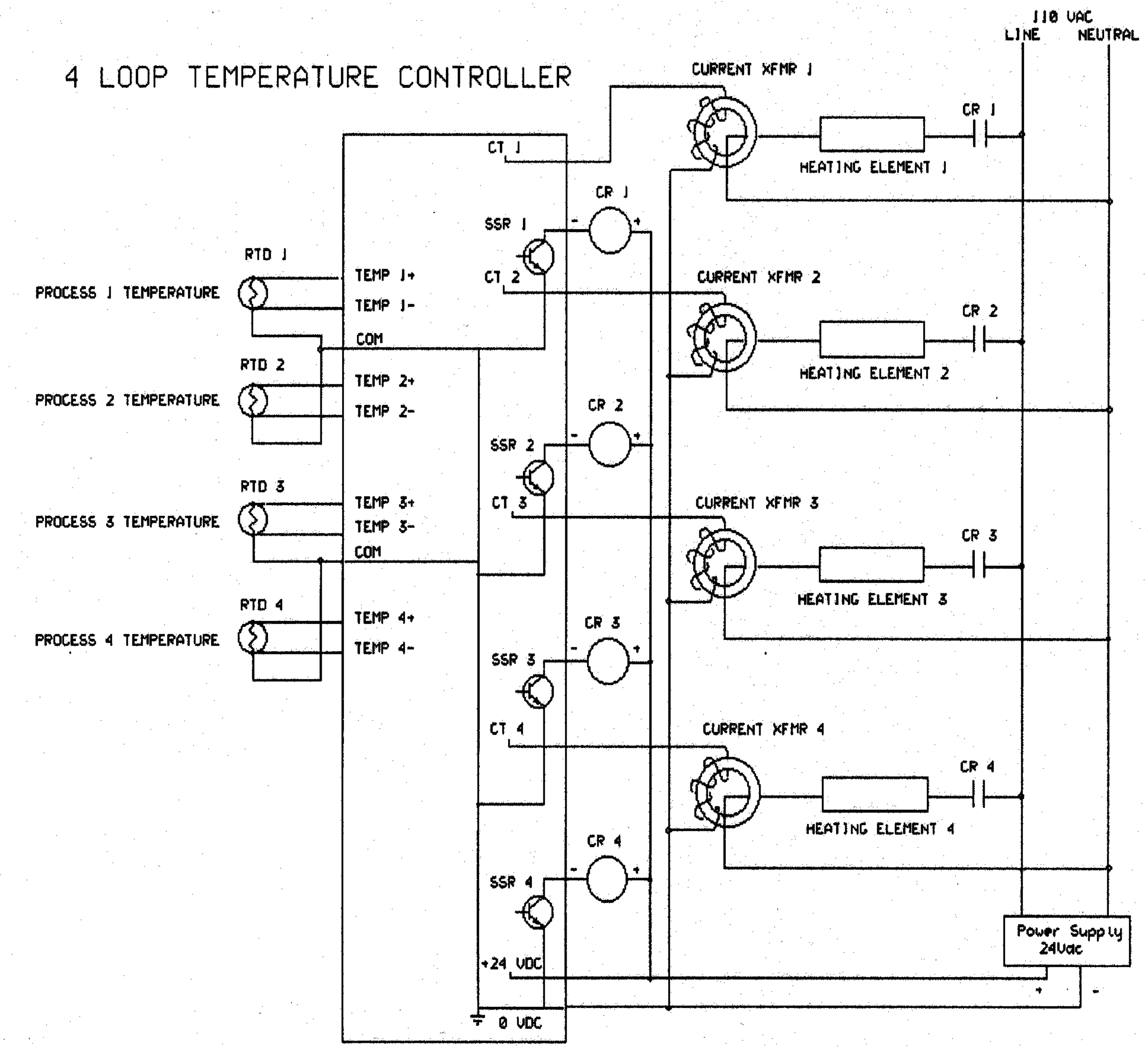
There can be up to 8 Four Loop Temperature Controllers per system. The temperature controller must be installed in the CPU base.



LED STATUS INDICATORS

TB	On when I/O terminal block is loose or missing.
24V	On if no external 24 VDC power or if analog circuit failed.
RUN	This LED toggles every second under normal operation.
OK	On after Controller completes self diagnostics.
OUT	On when corresponding heater **Output** is on.
AT	On when corresponding loop is **Auto Tuning**.
HB	On when corresponding **Heater Burn-out** has been detected. When a user supplied current ttransformer is connected, both shorted (current when output is off) and open (current does not flow when output is on) heater loads are detected.
ALM	On when corresponding loop has a temperature **Alarm** condition. Possible alarms are temperature high, temperature low and temperature has exceeded the deviation limit from the programmed temperature SetPoint.

RTD CONNECTION DIAGRAM



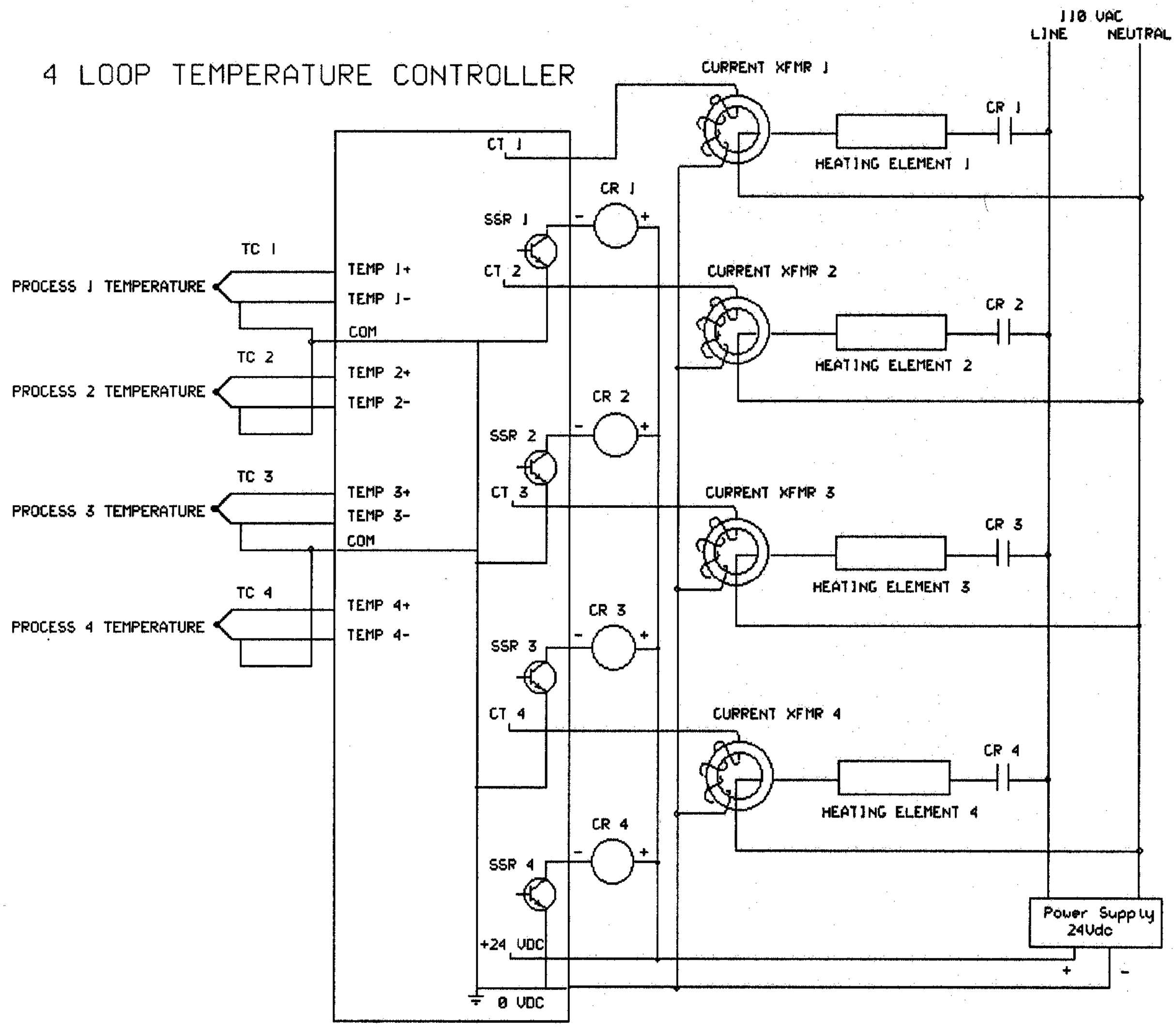
Notes: Accurate lead wire compensation requires that the three wires which connect an RTD to the Controller be exactly the same resistance (a 3.7' difference in 26 AWG lead length will introduce a .2 °F error).

If a four wire RTD is used, leave unconnected one of the positive side leads (only one wire should be connected to TEMP+).

Ground the shield drain wire only at the sensor end.

Observe the warning on page 2.2.

THERMOCOUPLE CONNECTION DIAGRAM



Notes: Ground the shield drain wire at one end only.

For grounded thermocouples, connect shield at the sensor end.

For ungrounded thermocouples, connect shield to the COM terminal of the F4-4LTC Temperature Controller module.

COM and 0 VDC are internally connected. Observe the warning on page 2.2.

GROUNDED VS UNGROUNDED THERMOCOUPLES

Grounded Thermocouple Assembly

A grounded thermocouple provides better response time than an ungrounded thermocouple because the tip of the thermocouple junction is in direct contact with the protective case.

Ungrounded Thermocouple Assembly

An ungrounded thermocouple is electrically isolated from the protective case. If the case is electrically grounded (for example, by the conduit) it provides a low impedance path for electrical noise to travel. In this configuration, the ungrounded thermocouple provides a more stable and accurate measurement in an electrically noisy area.

Exposed Grounded Thermocouple

In some cases, the thermocouple does not have a protective case and is connected directly to a device at a slightly different potential voltage. In this configuration, grounding the thermocouple will assure that the thermocouple remains within the ±5V common mode operating range of the module.

Because a thermocouple is essentially just a wire, an exposed grounded thermocouple also provides a low impedance path for electrical noise. This noise is first filtered by a single ended analog filter ahead of the precision analog to digital converter. Following the converter, the noise is next filtered by a Sinc3 (or (Sinx/x)3) response digital filter which has >100dB of 50 Hz and 60 Hz rejection.

MAXIMIZING THERMOCOUPLE MEASUREMENT PRECISION

Ambient Temperature Variations

The FACTS Engineering Temperature Controller module has been designed and tested to operate within specifications over a 0 to 60 °C ambient temperature range.

Thermocouple cold junction compensation is calibrated for operation in a still air environment. If used in an application with forced convection cooling (such as an enclosure with air circulated by a fan) then 2-3 °C of error is typically introduced into the cold junction compensation circuit. In this case, ladder logic can be used to correct SetPoint and indicated temperature values.

To maintain specifications, external devices must be prevented from creating a temperature gradient across the terminal block. If an external device releases heat into one end of the terminal block, small channel to channel reading variations may occur. Heat generating devices should generally be mounted above and away from the Temperature Controller.

If the module is exposed to abrupt temperature changes (such as opening the control system enclosure door) it may take several minutes for the automatic cold junction compensation circuit and terminal block to stabilize. Errors introduced due to abrupt ambient temperature changes normally will be less than 4 °C.

Thermocouple Wiring Distance Limitations

The maximum resistance of the thermocouple should be kept below 1000Ω. This will assure that errors, induced by the small amount of burn-out detection current which flows through the thermocouple, are less than .3 °C.

The following chart shows the maximum allowable distance for the Type 'K' thermocouple. The Type 'K' can be considered the worst case since it has the highest ohms per foot among the supported thermocouple types. For more information refer to the wire specifications of the thermocouple manufacturer.

WIRE GAUGE	OHMS PER FOOT	MAXIMUM DISTANCE
20	.586	1706 feet
24	1.490	671 feet
26	2.381	420 feet

DEDICATED V-MEMORY MAP

Each Temperature Controller has three dedicated V-Memory locations associated with it to specify the starting address of the Temperature Controller Parameters table, the number of temperature control loops enabled (scanned) for that module, and a location for the module to return configuration and self diagnostic error flags.

The dedicated V-Memory locations are only read by the Controller at power-up.

These memory locations must be made retentive if the module should operate when the PLC powers up in program mode.

Slot	Table Beginning Address	Operating Mode & Loops Enabled	Error Flag	Version
0	V7660	V7670	V7710	V7730
1	V7661	V7671	V7711	V7731
2	V7662	V7672	V7712	V7732
3	V7663	V7673	V7713	V7733
4	V7664	V7674	V7714	V7734
5	V7665	V7675	V7715	V7735
6	V7666	V7676	V7716	V7736
7	V7667	V7677	V7717	V7737

Table Beginning Address

The beginning address of the Controller parameter table is specified by a V-Memory pointer stored in the modules Table Beginning Address location. Normally the Table Beginning Address will be in retentive V-Memory, (memory above V2000).

Note	The range of valid Table Beginning Addresses is V1400 to V7500. The parameters table cannot be located in the higher user V-Memory locations provided on some DL405 CPUs. For example, the table cannot be located in the V10000 to V17777 memory range of a DL440 CPU.

Example:	To specify V5000 as the Temperature Controller parameter table beginning address for a Controller in slot 4, V7664 would contain the BCD number 5000.

Operating Mode and Loops Enabled

The Operating Mode and Loops Enabled location programs the operating mode and the number of loops enabled for the module. The most significant byte selects the Operating Mode and the least significant byte selects the number of Loops Enabled.

Operating Mode

There are four possible operating modes for all the enabled loops on the controller.

Normal	A 0 in the high byte selects normal 160 msec per channel operation. For most applications this provides the best trade off between speed and accuracy.
Slow	A 1 in the high byte selects the slower 800 msec per channel conversion time but provides the highest input stability and accuracy. If the PID Control Period (see page 2.20) is large (more than 4 seconds) then slow mode may be considered.
Fast	A 2 in the high byte selects a faster 32 msec per channel conversion time. If fast mode is selected, the resolution is reduced to ±2 °C. This mode is not recommended for PID applications.
Ck Cal	A 3 in the high byte selects the Check Thermocouple Calibration mode. This mode disables the module's active burn-out detection circuit so that you can connect a thermocouple calibrator to the module's temperature inputs.

Loops Enabled

Each Temperature Control loop uses 24 V-Memory locations of the Controller parameter table. The number of consecutive loops enabled controls the size of the block of V-Memory used by each Controller (24 to 96 words).

Example:	For a Controller in slot 0, V7670=0103 will select slow Operating Mode with only three loops enabled.

Controller in Slot 0, Slow Operating Mode, and 3 Loops Enabled.

Error Flag

The dedicated V-Memory Error location for each Controller is used to report configuration and diagnostic errors. This location is bit mapped. If any one of the fatal errors is detected at power up, the TB and 24V LEDs will flash back and forth until the error is cleared.

Hexadecimal Weight	Bit Number	Bit Description
Fatal Errors		
0001	0	Undefined
0002	1	On if Starting table address below user v-memory
0004	2	On if Starting table address too high
0008	3	On if More than 4 loops enabled
0010	4	On if Starting address is too high for number of loops
0020	5	On if Dedicated V-Memory Configuration Error
0040	6	On if Temperature Controller Configuration Error
0080	7	On if ROM Error, Incorrect Checksum
Warning Errors		
0100	8	Undefined
0200	9	Undefined
0400	10	Undefined
0800	11	Undefined
1000	12	Undefined
2000	13	Undefined
4000	14	Undefined
8000	15	On if the LTC CPU has gone through a Watch-Dog Time-Out

Example: If Error Flag contains 0004 then the starting table address is too high.

Version

The dedicated V-Memory Version location for each Controller holds the Controller's firmware Version number. The firmware version is written to this location after a reset.

Example A firmware version 1.01 Controller in slot 4 will return 0101 in V7734.

TEMPERATURE CONTROLLER LOOP CONFIGURATION MEMORY

All V-Memory values are in hexadecimal. Use the DirectSoft BCD/Hex or Binary data type to monitor loop bit mapped values, use decimal data type to display or monitor all other loop V-Memory values.

NOTE: The ***Direct*****Soft** decimal data type will convert a hexadecimal value, 0-0FFFFH, to it's decimal equivalent, 0-65535. It will not display negative numbers with a minus sign. Hegative numbers will appear as values greter than 32768. For example, -0.1 = 32768 (08001H) and -3276.7=65535 (0FFFFH).

The values in parenthesis in the following table show the allowable range for that V-Memory location. The values are shown after the hexadecimal to integer conversion and include the location of the implied decimal point.

Temperature values range from -3276.7 to +3276.7. If a temperature is negative the most significant bit in the V-Memory location is set. Temperature values are selectable for units of either degrees C or degrees F.

TEMPERATURE CONTROLLER LOOP CONFIGURATION MEMORY MAP, 1 LOOP

Decimal Offset	Example V-Mem.	Description	Units
0-1 Read continually			
0	V5000	Mode Word	bit mapped
1	V5001	Temperature Setpoint	± 3276.7 °C/°F
2	V5002	Output Bias	0.0-100.0% or 0-4095
3-5, Written after each temperature acquisition			
3	V5003	Output	0.0-100.0% or 0-4095
4	V5004	Alarm Word	bit mapped
5	V5005	Process Temperature	± 3276.7 °C/°F
6-8, Read if Mode Word bit 0 is set (Written by Controller after Auto Tune completion)			
6	V5006	Gain (Proportional)	0.0-6553.5
7	V5007	Reset (Integral)	0-65535 seconds
8	V5010	Rate (Derivative)	0-65535 seconds
9-23, Read if Mode Word bit 0 is set			
9	V5011	Low Alarm	± 3276.7 °C/°F
10	V5012	High Alarm	± 3276.7 °C/°F
11	V5013	Deviation Alarm	0- 3276.7 °C/°F
12	V5014	Alarm Deadband	0.1-50.0 °C/°F
13	V5015	Setpoint Low Limit	± 3276.7 °C/°F
14	V5016	Setpoint High Limit	± 3276.7 °C/°F
15	V5017	Input Type	(0=J, 1=E, 2=K, 3=R, 4=S, 5=T) (6=B, 7=N, 20=C) (26=0-5V, 27=±5V) (29=0-156.25mV, 30=±156.25mV) (8=European Pt100, 9=American) (10=European Pt1000) (11=CU-10Ω, 12=CU-25Ω)
16	V5020	PID Control Period	0.5-99.9 seconds
17	V5021	ON/OFF Hysteresis	0.1-3276.7 °C/°F
18	V5022	Temperature Calibration Adjustment	± 3276.7 °C/°F
19-23	V5023-V5027	Reserved for Future Feature Enhancements	

TEMPERATURE CONTROL PARAMETER DESCRIPTIONS

Bit Mapped Mode Word (V5000)

The bit mapped Mode Word allows you to enable and disable features, enter new PID parameters, enter new Alarm Parameters, and specify the format of the output word. There is one Mode Word per loop so that each loop can be programmed independently. This location is continually read by the temperature controller.

Hexadecimal Weight	Bit Number	Description
0001	0	Turn ON to Read PID and Alarm parameters from V-Memory, the module turns OFF the bit after the parameters are read
0002	1	ON = Reverse Acting (cooling) OFF = Direct Acting (heating)
0004	2	ON = Temperature Units °C OFF = Temperature Units °F
0008	3	ON = Output Format is analog value 0-4095 (@ V5003) OFF = Output Format is 0.0-100.0% (@ V5003)
0010	4	ON = PID Control OFF = ON/OFF Control
0020	5	ON = Deviation Alarm Enable (@ V5013)
0040	6	ON = SetPoint Clamp Enable (@ V5015 and @ V5016)
0080	7	ON = Heater Current Alarm Enable
0100	8	ON = Start Auto Tune / Module turns OFF the bit when Auto Tune succesfully completes OFF = Stop Auto Tune
0200	9	ON = Auto Tune for PI Control only (force Rate=0)
0400	10	ON = Minimize Oscillation OFF = Faster Response
0800	11	Not implemented, reserved for future use. Do not write 1s to reserved bits. These bits may be used in the future to enable new features.
1000	12	
2000	13	
4000	14	ON = Force Heater Output OFF (manual over-ride)
8000	15	ONN = Force Heater Output ON (manual over-ride)

Usage of Mode Bits

Turn on bit 0 whenever any of the PID or alarm setup parameters are changed. The Temperature Controller automatically clears this bit after the new setup parameters have been loaded.

Turn off bit 1 if heating control action is required. This will cause the output to increase when the temperature is below the SetPoint. Turn on bit 1 for cooling control. In this case, the output will increase when the temperature is above the SetPoint.

Turn on bit 2 for temperature units of degrees C. All temperature units have a single implied decimal point and are in the range -3276.7 to +3276.7. Negative values appear as values greater than 32768 (8000H).

Turn on bit 3 when the controller output commands an analog output module.

Turn on bit 4 for PID mode. See page 5.2 for a description of ON/OFF and PID control modes.

Turn on bit 5 to enable the Deviation Alarm. See page 2.18 for a description of the Deviation Alarm.

Turn on bit 6 to enable clamping of the SetPoint. For the loop 1 example, these are the values at V5015 (low limit) and V5016 (high limit).

Turn on bit 7 to enable heater current alarms. Open and shorted heater outputs can be detected when an external current transformer is used.

Turn on bit 8 to enable automatic calculation of the PID controller settings. The Temperature Controller automatically clears this bit when Auto Tune is done. Clear this bit to turn off Auto Tune prematurely.

Turn on bit 9 to Auto Tune for proportional and integral (PI) control only. This forces the PID Rate term to zero.

Turn on bit 10 to select an Auto Tune algorithm which will calculate PID controller settings optimized for minimal oscillation. When off, the calculated settings will be optimized for fastest response. Most temperature control applications should be auto tuned with this bit off. If on, the size and duration of the Auto Tune caused process disturbance is greatly increased.

Turn on bit 14 to force off the controller output. Turn on bit 15 to force the output on. Auto Tune is canceled and PID control is disabled if either of the over-ride bits are on. To provide a bumpless transfer from manual to automatic mode, it may be necessary to manually change the bias value (V5002).

Temperature SetPoint (V5001)

The Temperature SetPoint is the temperature you want the Process to be at. This location is continually read by the temperature controller.

Output Bias (V5002)

Output Bias or Manual Reset is the result of the integral control action of the PID Temperature Controller. It is the integral of the error over time and is added to the Output (V5003). Bias accommodates SetPoint and load changes by eliminating steady state errors. It is sometimes called automatic reset.

Manual Reset may be used to speed up the automatic reset operation. For example, a large increase in the SetPoint may cause the Bias to become too large. In this case, the temperature will overshoot the SetPoint. To prevent this, a predetermined value can be written to the Output Bias location as the temperature approaches the SetPoint.

Output Bias is also used to provide Feed Forward in anticipation of a process disturbance. For example, this disturbance could be the addition of colder fluid or a change in flow rate of the fluid being heated. In both cases the bias could be increased to provide additional heat to stabilize the temperature due to the disturbance.

Output (V5003)

The Output is the calculated result of the control algorithm based on the current SetPoint, process temperature, and the control type (ON/OFF or PID). The format of the output is 0.0 to 100.0% when bit 3 of the Mode Word is off or 0 to 4095 when bit 3 of the Mode Word is on. This location is written by the temperature controller after each loop update. The discrete time proportioned output status is also written to bit 15 of the Alarm Word.

Bit Mapped Alarm Word (V5004)

The bit mapped Alarm Word reports the status of the programmed alarms, the temperature sensor, and the built-in output. It is written to by the temperature controller after each temperature acquisition.

Hexadecimal Weight	Bit Number	Bit Description
0001	0	ON = Temperature Low Alarm
0002	1	ON = Temperature High Alarm
0004	2	ON = Temperature Deviation Limit Alarm
0008	3	ON = Broken RTD or Thermocouple (Burn-out detected)
0010	4	ON = No Heater Current Alarm (open or disconnected)
0020	5	ON = No Heater Current Control Alarm (output shorted)
0040	6	ON = Auto Tune Fault (unable to tune loop)
0080	7	Watch-Dog Bit, Toggles every temperature acquisition
0100	8	Auto Tune Sequence Status, A
0200	9	Auto Tune Sequence Status, B
0400	10	Undefined
0800	11	
1000	12	
2000	13	
4000	14	
8000	15	ON when Loop Output is ON (time proportioned output status)

Process Temperature (V5005)

The Process Temperature is the current temperature reported by the thermocouple or RTD input device plus the Temperature Calibration Adjustment value (V5022). This location is written to by the temperature controller after each loop update.

Gain (V5006)

Gain specifies the Proportional value used in the PID control algorithm. Some temperature controllers have a proportional band adjustment instead of a Gain adjustment. Gain is the inverse function of the proportional band. This means that the gain settings of 5, 1, and .5 would be equal to the proportional band settings of 20, 100 and 200% of temperature span. Gain is read by the temperature controller when bit 0 of the Mode Word is set, or written by the controller after gain has been calculated by the Auto Tune feature.

If you are accustomed to working with proportional band (PB) values expressed in temperature units you may use the following formula to convert PB in °C or °F to Gain.

Gain = 1310.7/PB (°C or °F)
Example: PB = 100 (°C or °F), Gain = 1310.7/100 = 13.1 (V5006 = 131)

PB (°C or °F) = 1310.7/Gain
Example: Default Gain = 200.0 (V5006=2000), PB = 1310.7/200.0 = 6.6 (°C or °F)

Reset (V5007)

Reset specifies the Integral action used in the PID control algorithm. This integral control action is sometimes called Automatic Reset. A value of 0 disables the Integral term. Reset is read by the temperature controller when bit 0 of the Mode Word is set, or written by the controller after reset has been calculated by the Auto Tune feature.

Rate (V5010)

Rate specifies the Derivative value used in the PID control algorithm. A value of zero disables the Derivative term. Rate is read by the temperature controller when bit 0 of the Mode Word is set, or written by the controller after rate has been calculated by the Auto Tune feature.

Temperature Low Alarm (V5011)

The Temperature Low Alarm occurs when the temperature falls below the value programmed in this location. This value is read by the temperature controller when bit 0 of the Mode Word is set.

Temperature High Alarm (V5012)

The Temperature High Alarm occurs when the temperature rises above the value programmed in this location. This value is read by the temperature controller when bit 0 of the Mode Word is set.

Temperature Deviation Alarm (V5013)

The Temperature Deviation Alarm occurs when the temperature is further from the SetPoint than the value programmed in this location. Bit 5 of the Mode Word enables reporting of this alarm. If bit 5 of the Mode Word is not set then the Temperature Deviation Alarm will not be reported. This value is read by the temperature controller when bit 0 of the Mode Word is set.

Alarm Deadband (V5014)

The Alarm Deadband lets you program a deadband around each alarm. Deadband prevents alarms from chattering when near an alarm limit. This value is read by the temperature controller when bit 0 of the Mode Word is set.

SetPoint Low Limit (V5015)

Bit 6 of the Mode Word enables SetPoint clamping. If it is on then the SetPoint Low Limit is the lowest value that can be used as a SetPoint. If a lower SetPoint is programmed (V5001) then it will be clamped to the SetPoint Low Limit. This value is read when bit 0 of the Mode Word is set.

SetPoint High Limit (V5016)

Bit 6 of the Mode Word enables SetPoint clamping. If it is on then the SetPoint High Limit is the highest value that can be used as a SetPoint. If a higher SetPoint is programmed (V5001) then it will be clamped to the SetPoint High Limit. This value is read when bit 0 of the Mode Word is set.

Input Type (V5017)

Input Type specifies the temperature or voltage input device being used. This parameter is used in conjunction with the module jumper settings described on page 2.2. RTDs, Voltage Inputs or Thermocouples cannot be mixed on the same module. Any combination of thermocouple types K, J, E, and N may be used. Also types R, S, B, and C may be used on the same module. The Type T thermocouple and all the voltage input ranges cannot be mixed on the module. Input Type is read by the controller when bit 0 of the Mode Word is set.

Thermocouple Input Types: 0=J, 1=E, 2=K, 7=N or 3=R, 4=S, 6=B, 20=C or 5=T

Voltage Input Types: 26=0-5V or 27=±5V or 29=0-156.25mV or 30=±156.25mV

Input Type codes for 100Ω platinum RTDs are 8=European and 9=American. The Input Type code for a 1000Ω European curve platinum RTD is 10. All RTDs used on the same module must be the same resistance range (you can mix types 8 and 9 since they are both 100Ω). European 100Ω and 1000Ω RTDs are sometimes referred to as Pt100 and Pt1000. They both have an alpha value of ∞ = .003850. American RTDs are sometimes referred to as jPt100 and have an alpha value of ∞ = .003916. The alpha value is the mean temperature coefficient of the Resistance Temperature Device (RTD) and is normally .003850. Both 10Ω and 25Ω copper RTDs are supported via Input Type codes 11 and 12 respectively.

RTD Input Types: 8=Pt100,9=jPt100 or 10=Pt1000 or 11=CU-10Ω or 12=CU-25Ω

Note To prevent an invalid combination of Input Types, power cycle the controller after changing an Input Type. Valid combinations are: K,E,J,N or R,S,B,C or Pt100,jPt100. All other types are unique.

PID Control Period (V5020)

The PID Control Period specifies the time period that the output will be applied to. This value is also used as the sample rate for the PID calculation. It is read by the temperature controller when bit 0 of the Mode Word is set and only applies to PID control. The default PID Control Period is 2.0 seconds (V5020=20).

If 1 second is specified as the PID Control Period then there will be 50 (1/.020) 20 millisecond periods. If the PID output is 100% then the output will be on for all 50 periods. If the PID output is 50% then the output will be on for 25 periods. If the PID output is 25% then the output will be on for 12 periods. The output time is accurate to within one PLC scan time.

a) Maximum Control Period

When the Output is a mechanical relay, the Control Period may be increased to lengthen relay life. As a rule of thumb, the PID update rate should be 4x to 10x faster than the loop deadtime. The deadtime of the loop is approximately the temperature speed of response to a change in output. For example, assume the output is increased 20% (V5002=V5002+200) at time zero. Thirty seconds later the temperature has increased 1 degree. Thus the maximum Control Period is safely 30/10x = 3 seconds (V5020=30). Therefore a shorter Control Period of 2 seconds should be used.

b) Minimum Control Period

Use 2 seconds (V5020=20) for the minimum Control Period unless the temperature speed of response to a change in output dictates a smaller value (see Maximum Control Period above). The minimum value which may be specified is .5 seconds (V5020=5).

How tightly a fast loop can be controlled is limited by the PLC scan time. The actual time proportioned output will be on from 0 to +1 scan time more than the calculated output on time.

Normally the scan time is not a problem because it is small compared to the Control Period. For example, the output error for a .5 second Control Period will range from 0 msec (0%) to +20 msec (+4%) for a 20 msec PLC scan time.

However, the scan time can introduce a significant source of error if the scan time is large and the Control Period is small. For example, the output error for a .5 second Control Period can be up to 25% for a 125 msec PLC scan time.

As a rule of thumb, the Control Period should be at least 10 times the PLC scan time. In the last example, it should be 1.2 seconds minimum.

ON/OFF Hysteresis (V5021)

The ON/OFF Hysteresis is a deadband around the SetPoint where the output will not change. The minimum hysteresis is .1. The default hysteresis values are .5 °C and 1.0 °F. This value only applies to ON/OFF control. This value is read by the temperature controller when bit 0 of the Mode Word is set.

Temperature Calibration Adjustment (V5022)

Temperature Calibration Adjustment is a ± 3276.7 °C or °F value which is added to the controller measured Process Temperature. This location can be used to remove inaccuracies due to thermocouple cold junction compensation errors (see page 2.7) and temperature input device errors (typical thermocouple device inaccuracy is ±1 to ±3 °C). If no adjustment is required then this location should be set equal to zero.

Process Temp. (V5005) = Actual Temp. (measured) + Cal. Adjustment (V5022)

Examples:
Actual Temperature = 24.6 °C
Process Temperature = 25.2 °C
Temperature Calibration Adjustment = 32768+6 = 32774 = -.6 °C

Actual Temperature = 28.2 °C
Process Temperature = 26.3 °C
Temperature Calibration Adjustment = 19 = +1.9 °C

TEMPERATURE CONTROLLER MEMORY MAP, 4 LOOPS

The following example V-Memory map shows the addressing for all four loops of a Temperature Controller Module with a Table Beginning Address of V5000. Any V-Memory address maybe specified as the loop table starting address for a given module. Normally retentive V-Memory is used to store loop parameters (V2000-V7377).

LOOP 1	LOOP 2	LOOP 3	LOOP 4	DESCRIPTION
5000	5030	5060	5110	Mode Word
5001	5031	5061	5111	SetPoint
5002	5032	5062	5112	Bias
5003	5033	5063	5113	Output
5004	5034	5064	5114	Alarm Word
5005	5035	5065	5115	Temperature
5006	5036	5066	5116	Gain
5007	5037	5067	5117	Reset
5010	5040	5070	5120	Rate
5011	5041	5071	5121	Low Alarm
5012	5042	5072	5122	High Alarm
5013	5043	5073	5123	Deviation Alarm
5014	5044	5074	5124	Alarm Deadband
5015	5045	5075	5125	SP Low Limit
5016	5046	5076	5126	SP High Limit
5017	5047	5077	5127	Input type
5020	5050	5100	5130	Control Period
5021	5051	5101	5131	Hysteresis
5022	5052	5102	5132	Calibration Adj
5023	5053	5103	5133	Spare
5024	5054	5104	5134	Spare
5025	5055	5105	5135	Spare
5026	5056	5106	5136	Spare
5027	5057	5107	5137	Spare

CHAPTER 3: SUPPORTING LADDER LOGIC

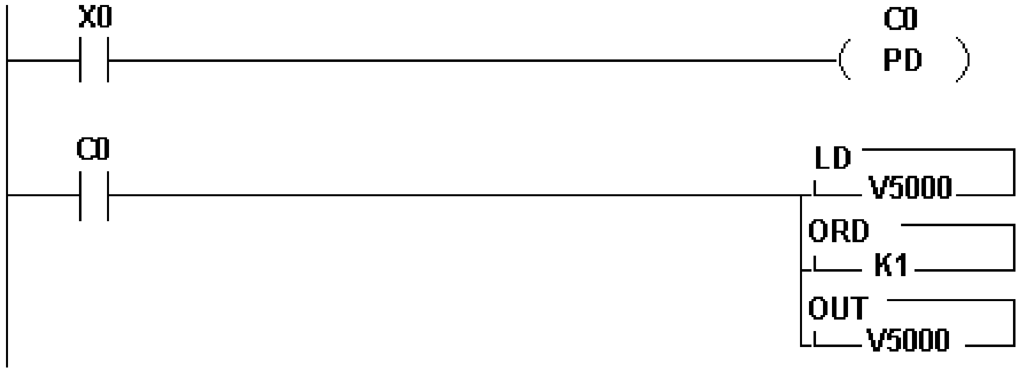
Minimal or no ladder logic is required in most applications. The following ladder logic examples extend the capabilities of the Temperature Controller.

SLOT DEPENDENT CONFIGURATION

The rung below programs the slot dependent V-Memory locations for a F4-4LTC in Slot 4, Normal Operating Mode, and 4 Loops Enabled.

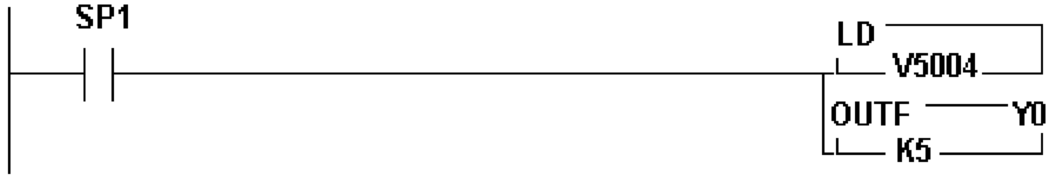
RE-READ LOOP PARAMETERS

If any of the PID or alarm parameters are changed then bit 0 of the mode word must be set in order for the Temperature Controller module to apply these new values. The logic below shows an example that uses X0 to set bit 0 of the mode word. A one-shot is used so that the Temperature Controller module does not constantly re-read these parameters. You can change the X and C references to whatever best meets your application needs. If your loop does not start at V5000 then you need to change the V-Memory reference accordingly.



ALARM WORD DECODING

The rung below copies the alarm bits for loop 1 (V5004) into Y0-Y4.



Y0	Temperature Low Alarm
Y1	Temperature High Alarm
Y2	Temperature Deviation Limit Alarm
Y3	Broken RTD or Thermocouple (Burn-out detected)
Y4	No Heater Current Alarm (open or disconnected)

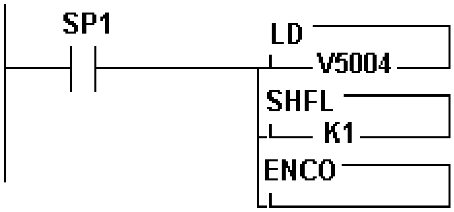
ALARM WORD ENCODING

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 Temperature Alarm" will override a "Temperature Deviation Alarm". A "Broken Transmitter Alarm" will always be recognized since in this case the Temperature Controller disables all other alarms and loop processing.

Alarm Word

Encoded BCD Number	Bit Number	Description
1	0	Temperature Low Alarm
2	1	Temperature High Alarm
3	2	Temperature Deviation Limit Alarm
4	3	Broken RTD or Thermocouple (Burn-out detected)
5	4	No Heater Current Alarm (open or disconnected)
6	5	No Heater Current Control Alarm (output shorted)



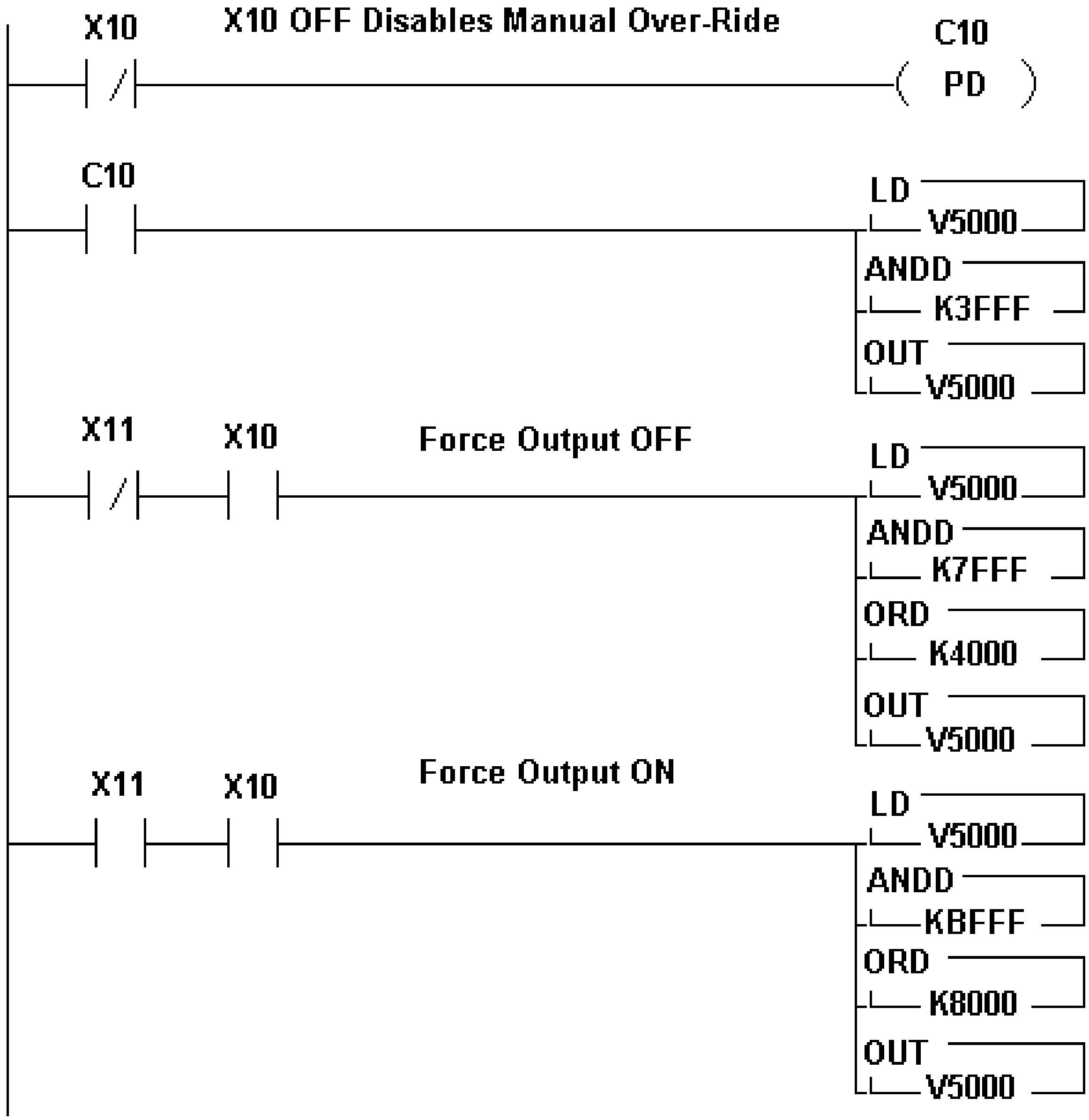
Load Alarm Word for Loop 1 to accumlator

Shift bits 1 position to the left for ENCODE

Position of 1st bit is put in accumulator

FORCE OUTPUT ON/OFF (MANUAL OVER-RIDE)

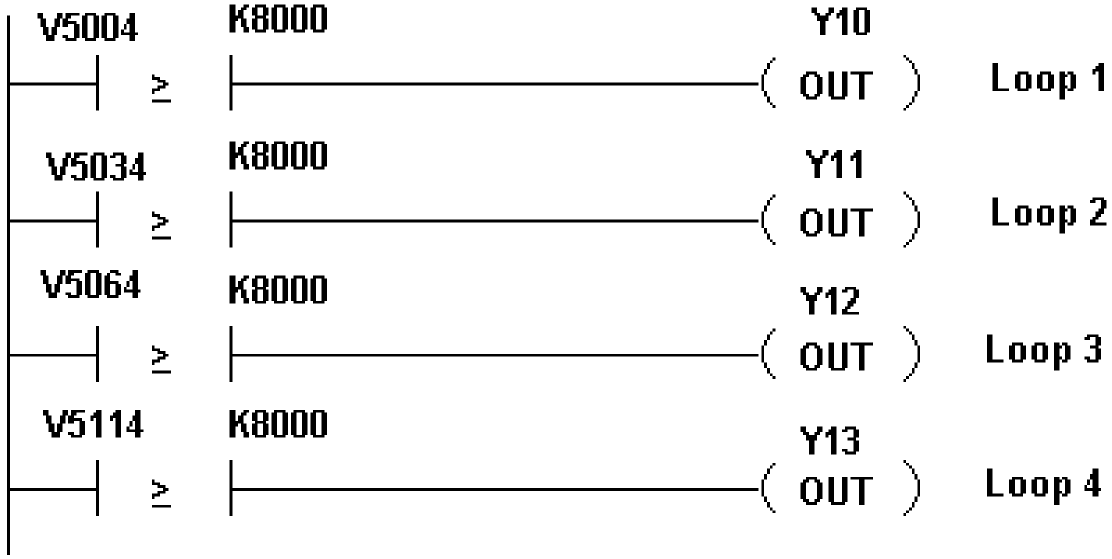
The following example uses two contacts to implement manual over-ride. X10 is used as a selector switch, if it is OFF then manual over-ride is disabled if it is ON then manual over-ride is enabled. If X10 is ON then X11 selects which state to force the output, X11 OFF forces the output OFF, X11 ON forces the output ON. You can change the X and C references to whatever best meets your application needs. If your loop does not start at V5000 then you need to change the V-Memory reference accordingly.



DISCRETE OUTPUT STATUS

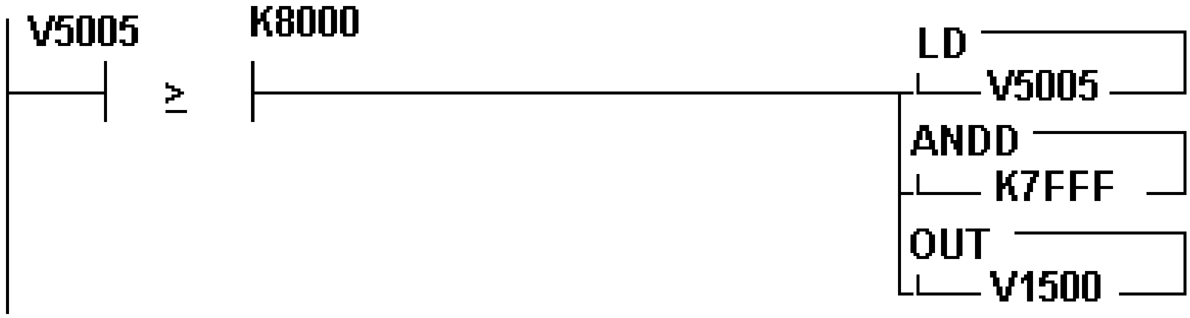
The status of the discrete time proportioned solid state relay outputs built into the Temperature Controller is also written to bit 15 of the Alarm Word. This allows you to use an AC Output or High Current Relay Output module in the PLC to directly control, for example, a heater.

The following example copies the output status from the Alarm Words of all four loops to the discrete outputs Y10 to Y13.



NEGATIVE TEMPERATURES

The following example is useful if you are working with negative temperatures. It simplifies the viewing of a negative number. The example converts the magnitude plus sign temperature indication to a magnitude only value and places it in an alternate V-Memory location. If your loop does not start at V5000 then you need to change the V-Memory reference accordingly.

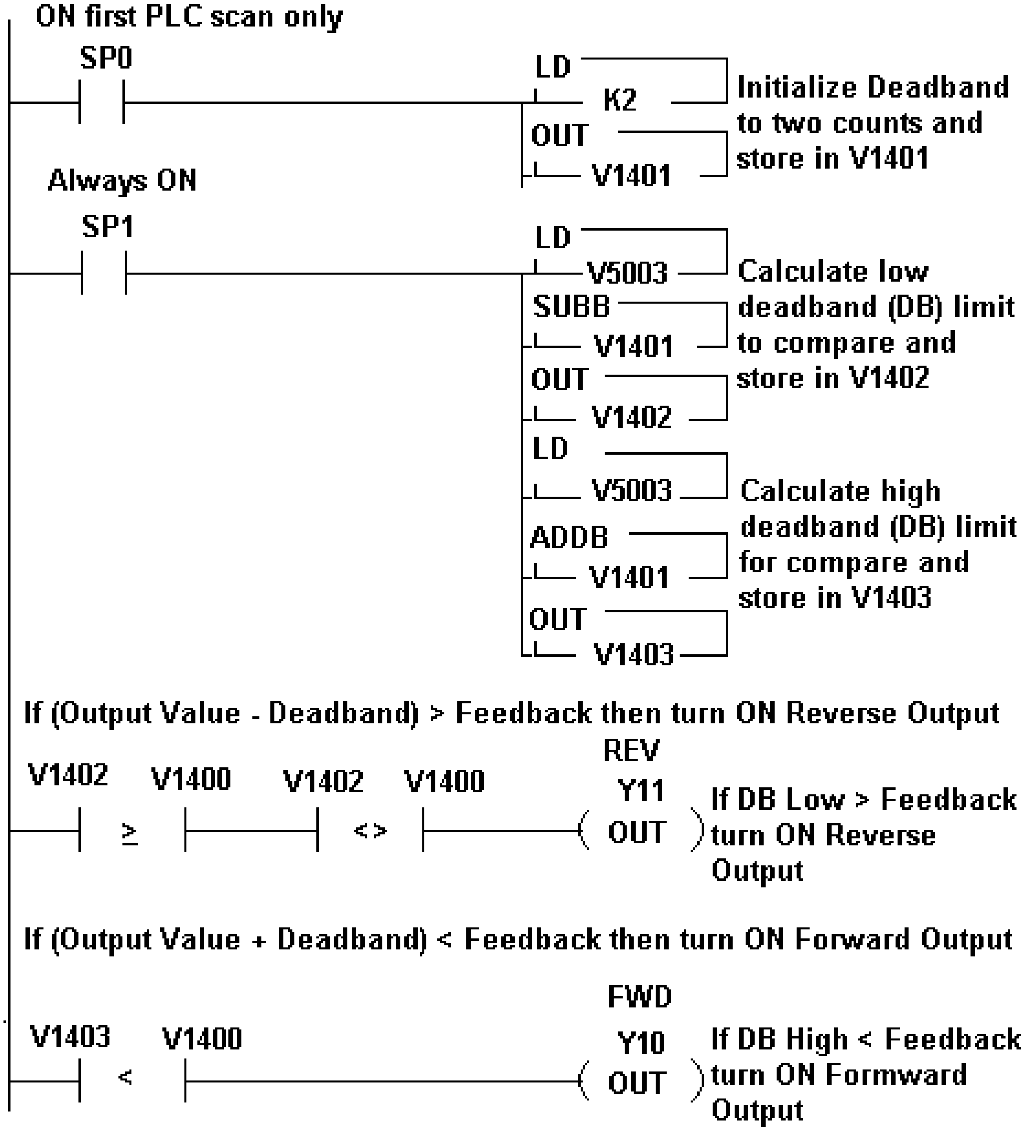


POSITIONING ACTUATOR CONTROL LOOPS

A reversible electric motor used to operate a valve is an example of a positioning actuator. This example will use the controller output in V5003 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 deadband (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.



SETPOINT RAMP AND SOAK

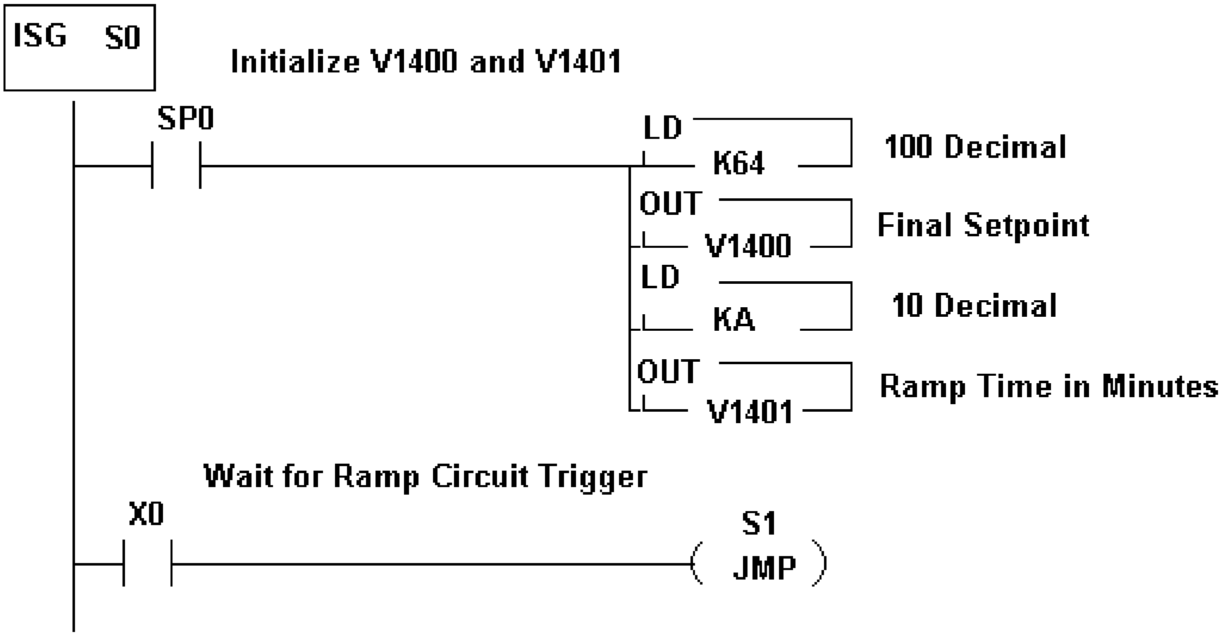
For each loop the user can program a Ramp or Soak of the SetPoint as shown in the following examples.

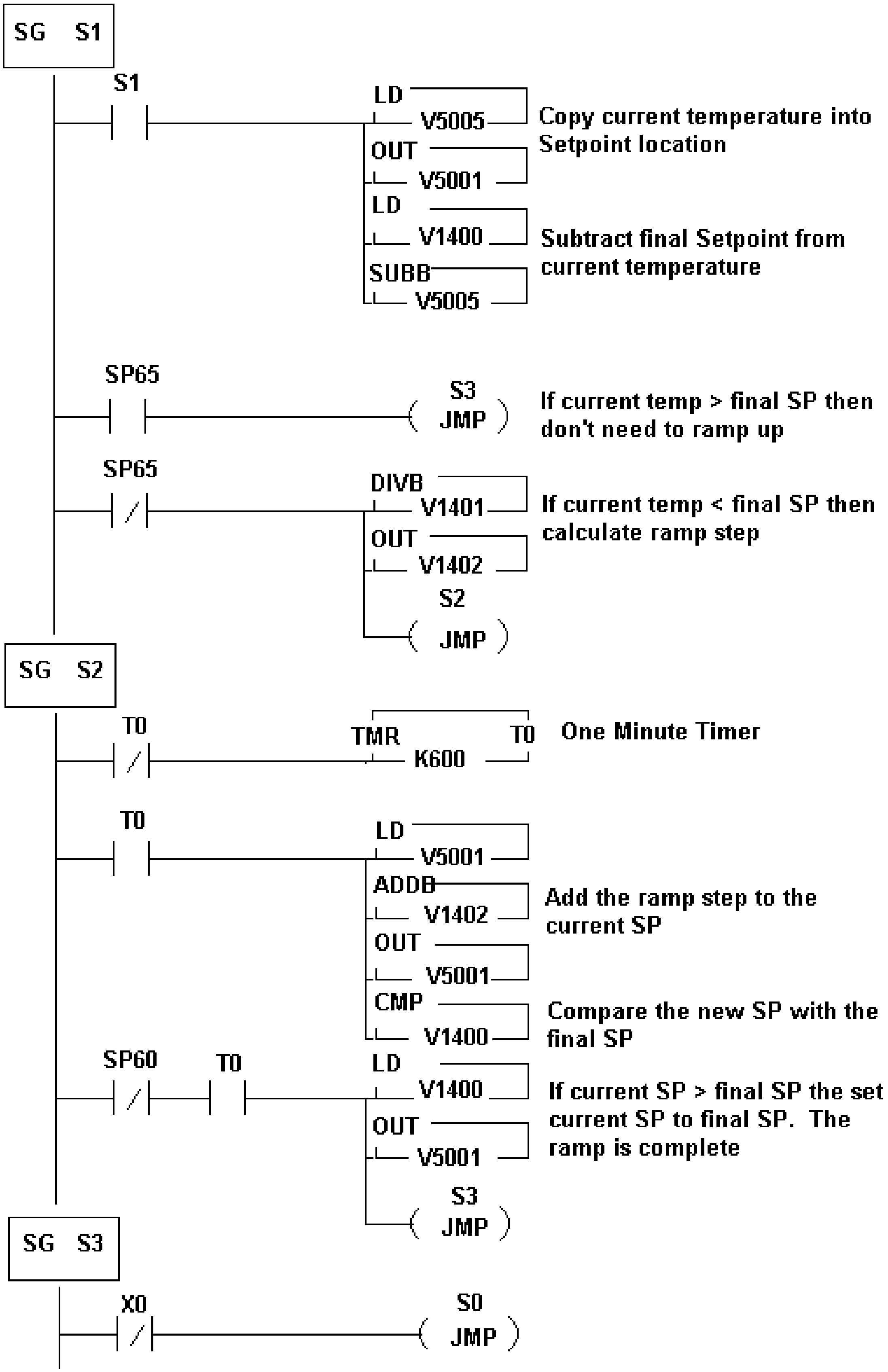
SetPoint Ramp

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 temperature is used as the initial SetPoint. It is obtained from the Temperature Controller parameter table for loop 1, V5005. The final SetPoint is in V1400 and the ramp time, in minutes, is stored in V1401.

The holding time at each step is fixed at one minute. X0 is a physical input that triggers the calculation of the ramp step, X0 could be replaced by any C (control relay) controlled by the user's program. The calculated ramp step is stored in V1402. The SetPoint is increased from the initial temperature value to the final SetPoint value. The example could easily be modified to ramp the SetPoint down to some lower final value.



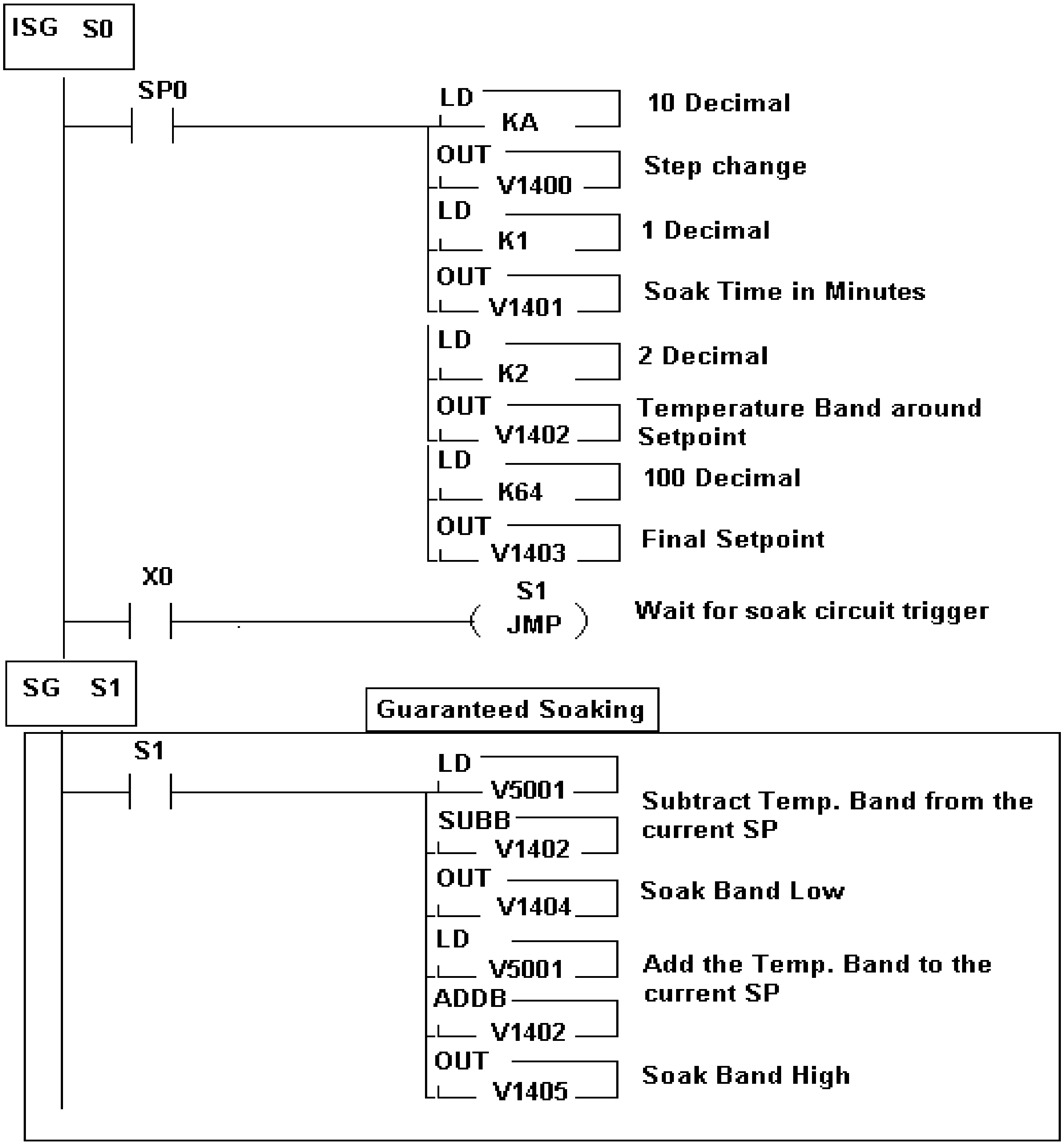

SG S1
S1
LD
V5005
OUT
V5001
LD
V1400
SUBB
V5005
Copy current temperature into Setpoint location
Subtract final Setpoint from current temperature
SP65
S3
JMP
If current temp > final SP then don't need to ramp up
SP65
DIVB
V1401
OUT
V1402
S2
JMP
If current temp < final SP then calculate ramp step
SG S2
T0
TMR
K600
T0
One Minute Timer
T0
LD
V5001
ADDB
V1402
OUT
V5001
CMP
V1400
Add the ramp step to the current SP
Compare the new SP with the final SP
SP60
T0
LD
V1400
OUT
V5001
S3
JMP
If current SP > final SP the set current SP to final SP. The ramp is complete
SG S3
X0
S0
JMP

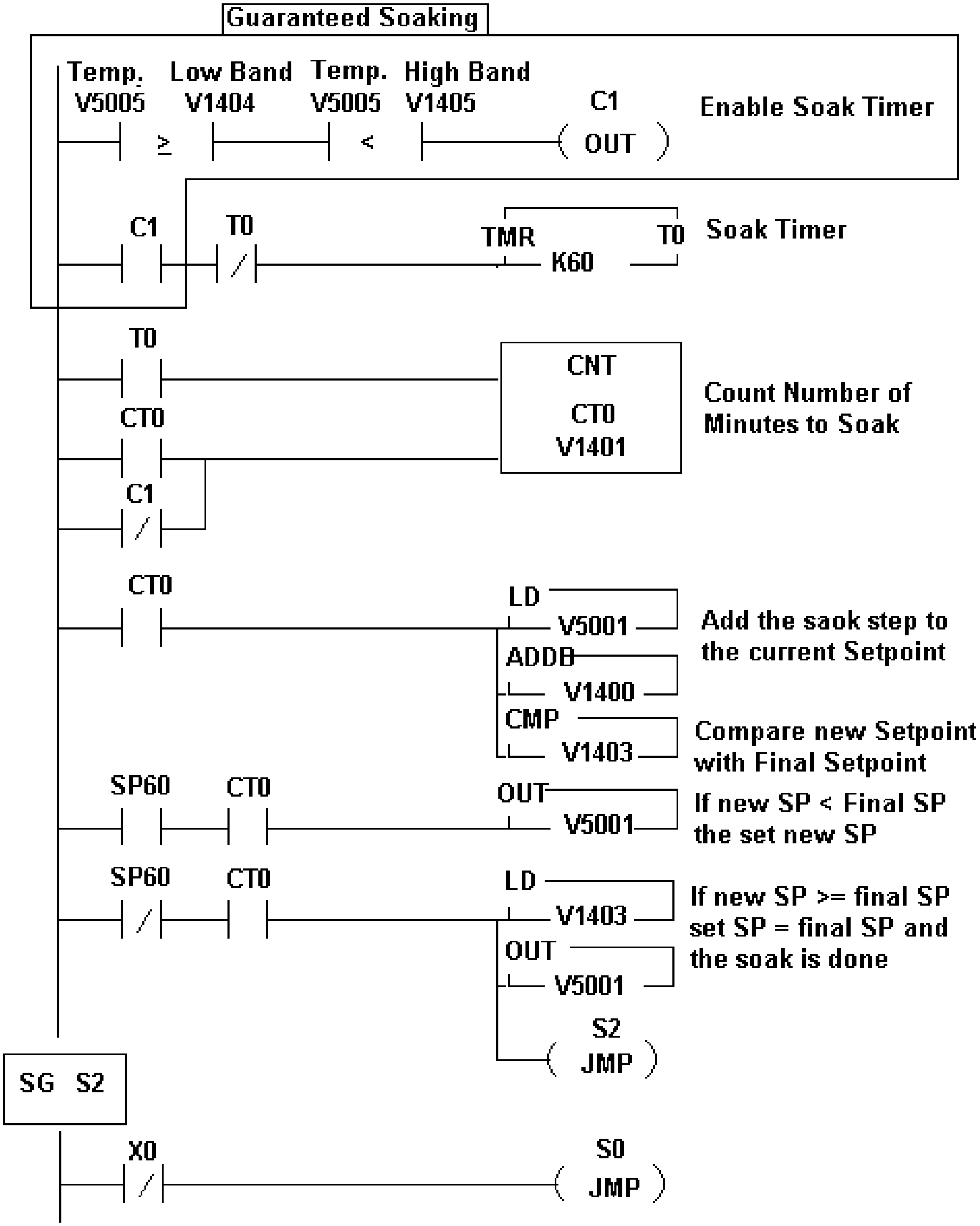
SetPoint Soak

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 temperature band around the SetPoint is stored in V1402. The final SetPoint is stored in V1403.

If guaranteed soaking is not desired then delete the Stage 1 logic marked 'Guaranteed Soaking' in the following example.




Guaranteed Soaking
Temp. V5005
Low Band V1404
Temp. V5005
High Band V1405
≥
<
C1
OUT
Enable Soak Timer
C1
T0
TMR
T0
K60
Soak Timer
T0
CT0
C1
CNT
CT0
V1401
Count Number of Minutes to Soak
CT0
LD
V5001
ADDB
V1400
CMP
V1403
Add the saok step to the current Setpoint
Compare new Setpoint with Final Setpoint
SP60
CT0
OUT
V5001
If new SP < Final SP the set new SP
SP60
CT0
LD
V1403
OUT
V5001
If new SP >= final SP set SP = final SP and the soak is done
S2
JMP
SG S2
X0
S0
JMP

3.10 SUPPORTING LADDER LOGIC

CHAPTER 4: LOOP TUNING

AUTO TUNE PROCEDURE

1. Configure the module for the type of Temperature Sensor (V5017). Then program the PID Control Period (V5020) and Temperature SetPoint (V5001).

   a) The default value for the PID Control Period of two seconds (V5020=20) is sufficient for most applications. See page 2.20 for a description of PID Control Period.

2. If heating control action is required then turn off bit 1 in the Mode Word (V5000). This will cause the output to increase when the temperature is below the SetPoint. Turn on bit 1 for cooling control. In this case, the output will increase when the temperature is above the SetPoint.

3. Make the temperature stabilize near the most commonly used SetPoint. Although this step is not necessary, the time required to tune the loop will be reduced if it is done. There are two ways to do this.

   a) The easiest way to stabilize the temperature at the SetPoint is to put the Temperature Controller in ON/OFF control mode (turn off bit 4 in the Mode Word). While in ON/OFF control mode, the Temperature Controller will estimate the required PID Output Bias based on the duty cycle of the Output. Note that it may be necessary to increase the ON/OFF Hysteresis so that the Output does not chatter as the temperature passes through the SetPoint. When the estimated Output Bias is nearly the same each time the Output cycles, proceed to step 4.

   b) If the process will not tolerate the Temperature Controller operating in ON/OFF control mode then select PID Gain and Reset values until the Temperature Controller begins to move the temperature closer to the SetPoint. Auto Tune Optimization on page 4.4 describes the effect Gain and Reset have on the PID controller. Force the solid state relay output on and off using bits 14 and 15 of the Mode Word (V5000) and manually adjust the Output Bias (V5002) to speed up stabilization.

4. Turn on PID Auto Tune by setting bits 4 and 8 in the Mode Word. Bit 8 should be set using a one-shot in ladder logic. The Temperature Controller turns off bit 8 when Auto Tune is done. Auto Tune may be aborted by turning this bit off. During Auto Tune, the process should be in a steady state condition (prevent load changes during Auto Tune).

5. After Auto Tune is done, the new calculated PID Temperature Controller settings for Gain (V5006), Reset (V5007), and Rate (V5010) will automatically be used.

6. If the settings calculated by Auto Tune are too aggressive (temperature overshoots or oscillates around the SetPoint too much following a disturbance) then re-tune the loop with bit 10 (minimize oscillation) turned on. If the large disturbance introduced into the process by this Auto Tune algorithm cannot be tolerated, then Auto Tune Optimization (page 4.4) or manual tuning (page 4.5) will be required.

AUTO TUNE SEQUENCE

The auto tune algorithm uses the following sequence of operation to calculate the controller settings. The state of the auto tune operation is reported by the Auto Tune Sequence Status bits A and B located in the Alarm Word (V5004).

1. Bring the temperature to within 1.0 °C (1.8 °F) of the SetPoint. At this step, the ATn LED will be urned ON and both Auto Tune Sequence Status bits A and B will be off.

2. Move the temperature 2 °C (3.6 °F) away from the SetPoint (decrease temperature if heating lop). At this step, the Auto Tune Sequence Status bit A will be on and B will be off.

3. Wait for the Output Bias to stabilize to within 1.0 °C (1.8 °F) of this temperature. At this step, the Auto Tune Sequence Status bit A will be off and B will be on.

4. Bump the output a constant 10%. At this step, both Auto Tune Sequence Status bit A and B will be on.

5. If bit 10 of the mode word is on (minimize oscillation) then the controller settings are calculated after the temperature stabilizes at the new output (this can take a very long time).

   If bit 10 of the mode word is off (faster response) then the controller settings are calculated long before the temperature stabilizes at the new output value.

AUTO TUNE TROUBLESHOOTING

Problem: Auto Tune stopped and the Auto Tune Fault bit in the Alarm word was turned on (bit 6).

Cause: During Auto Tune, the controller output reached the full scale positive limit (100%).

Solution: Choose a SetPoint so that Output is not near full scale limit.

Problem: Auto Tune "hangs up" during step 4 and never finishes.

Cause: When Auto Tune bumps the output 10% (V5002=V5002+100), the temperature must increase at least 1 degree C (1.8 degrees F).

Solution: If a 10% increase has little or no effect on the temperature then the loop gain is very large. In this case, PID Control may not offer any performance increase over ON/OFF Control. If ON/OFF Control is insufficient, then manual PID Tuning will be required. One method of manual PID tuning is described beginning on page 4.5.

Problem: Auto Tune "hangs up" during Auto Tune Sequence steps 1, 2, or 3 and never finishes.

Cause 1: One degree C of temperature instability due to noise pickup will prevent Auto Tune from completing successfully.

Solution 1: Possible solutions to this problem are:

Improve sensor wiring, shielding, and grounding and re-tune the loop.

Remove process disturbances which prevent the temperature from stabilizing (step 3 of the Auto Tune Sequence described above).

If the temperature cannot be stabilized to within one degree C then the loop must be tuned manually as described beginning on page 4.5. In this case, it is further recommended that the Rate term be forced to 0. This will prevent the temperature instability from causing erratic PID output.

Cause 2: The initial programmed PID Gain, Reset, and Rate values are inadequate.

Solution 2: Set Rate to zero and select PID Gain and Reset values until the Temperature Controller begins to move the temperature closer to the SetPoint. Auto Tune Optimization on page 4.4 describes the effect Gain and Reset have on the PID controller.

Problem: Auto Tune causes the temperature to deviate too far from the SetPoint.

Cause: Auto Tune must bump the output 10% in order to learn the process dynamics (step 4 of the Auto Tune Sequence). This may be too great a change in some applications.

Solution: Turn off Auto Tune at the maximum temperature deviation permitted by the application. Auto Tune will then estimate the controller settings based on the information gathered up to this point. The estimate will generally be inferior to the values which would have been calculated had Auto Tune completed normally. If the estimated values are insufficient then perform manual Auto Tune Optimization as described below.

AUTO TUNE OPTIMIZATION

A perfectly tuned loop will respond quickly with no overshoot. This is the Auto Tune goal. However, the auto tune algorithm cannot determine the perfect controller settings for every application. Manual optimization can be used to fine tune the controller settings for each application. For example, fine tuning can be used to increase response, minimize steady state errors, or reduce overshoots.

For example, some applications will require an aggressively tuned loop which will maintain the temperature very close to the SetPoint. An aggressively tuned loop will have higher Gain or lower Reset values. Note that the more aggressively a loop is tuned, the less tolerant it will be to process disturbances and changes in SetPoint. This is because high Gain or low Reset values may cause overshoot and oscillation of the temperature around the SetPoint.

The effect gain and reset have on the PID controller are:

1. Steady state error decreases with increasing gain.

2. Response speed increases with increasing gain.

3. Overshoot and oscillation increase with increasing gain.

4. Short reset times cause oscillations.

5. Long reset times cause slow response.

After changing a PID setting (V5006-V5010) remember to set bit 0 in the Mode Word so that the new settings will be used. To eliminate the effects of previous settings on the integral term it may be necessary to manual adjust the Bias (V5002).

USE AUTO TUNE TO BUILD RECIPES

A loop tuned for a particular SetPoint and load (for example mass or flow rate) may not respond as well under different process conditions. In order to have fast response with minimal overshoot over a wide range of operating conditions optimum controller settings may need to be determined in advance for different operating conditions. This is sometimes referred to as recipes.

1. The controller settings for a given steady state operating condition are determined using Auto Tune. Manual optimization of the controller settings can optionally be used to provide tighter control or different response characteristics.

2. Repeat the tuning procedure under various operating conditions.

3. Use the predetermined controller settings for each operating condition.

4. Use ladder logic to identify each operating condition and load the appropriate predetermined controller setting for that condition.

MANUAL PID TUNING

Some applications will require manual PID tuning. First time PID control user's should review the PID Fundamentals described in Appendix A. Also review Auto Tune Optimization above to gain an understanding of the effect that Gain and Reset have on the PID controller.

1. Configure the module for the type of Temperature Sensor (V5017). Then program the PID Control Period (V5020) and the Temperature SetPoint (V5001). See page 2.20 for a description of PID Control Period.

2. If heating control action is required then turn off bit 1 in the Mode Word (V5000). This will cause the output to increase when the temperature is below the SetPoint. Turn on bit 1 for cooling control. In this case, the output will increase when the temperature is above the SetPoint.

3. Set the Reset (V5007) and Rate (V5010) to zero to disable all integral and derivative action. Set the Gain (V5006) to 0200 (20.0). Set the PID Control Period (V5020) to 20 (2.0 seconds).

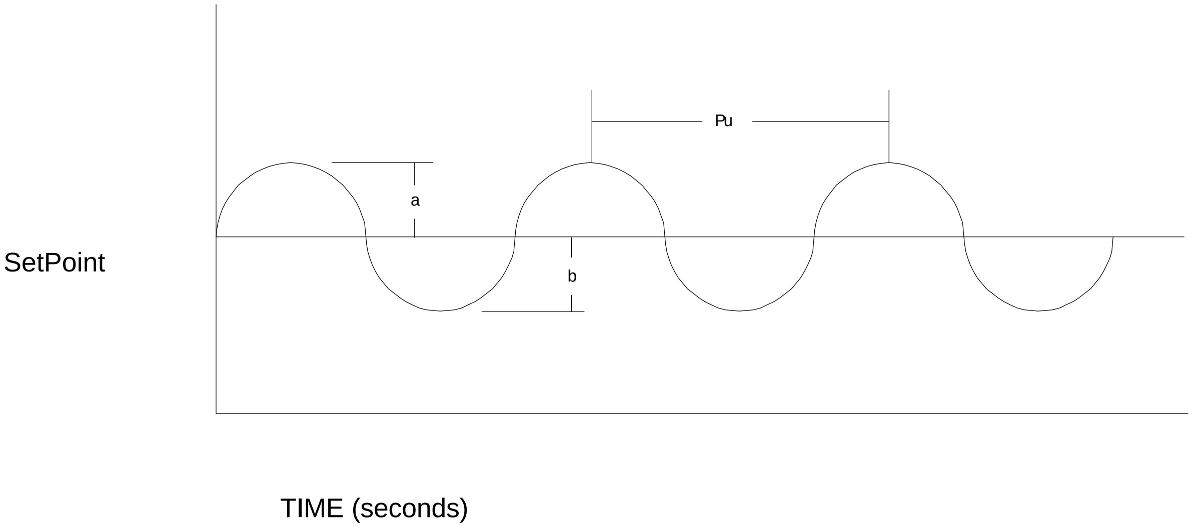
4. Make the temperature stabilize near the most commonly used SetPoint (two methods for doing this are described on page 4.1). Place the temperature controller in PID Control mode by turning on bit 4 in the Mode Word.

5. Prepare to plot the temperature as it varies with time (in seconds).

6. Generate an upset in the loop and adjust the Gain (V5006) until the temperature cycles with a constant amplitude (a/b = 1). If the amplitude increases (a/b < 1) following the upset then the Gain must be reduced. If the amplitude decreases (a/b > 1) following the upset then the Gain should be increased.

   An upset can be generated by changing the SetPoint. After the temperature begins to move towards the new SetPoint, return the SetPoint to the previous value.

7. The gain which produces oscillations with a constant amplitude is called the ultimate gain, Ku. The period of these oscillations is called the ultimate period, Pu.



8. Calculate the controller settings given the ultimate gain and period determined in step 7.

   Gain (V5006) = .6Ku

   Reset (V5007) = .5Pu

   Rate (V5010) = Pu/8

   For example, if the ultimate period is 140 seconds then the Reset value is 70 and the Rate value is 17.

9. Monitor the operation of the Temperature Controller with the new settings. Using the tips described in Auto Tune Optimization above, make any necessary refinements to the PID loop operation.

APPENDIX A: PID FUNDAMENTALS

PID CONTROL FUNDAMENTALS

This section describes the proportional, integral and derivative control actions (PID) of the Temperature Controller. The Four Loop Temperature Controller maintains the temperature of a process. This temperature is called the Process Variable (PV). The controller action is called the Output (sometimes referred to as the manipulated variable).

Proportional Control

Proportional Control action produces an output signal that is proportional to the difference between the SetPoint and the PV (sometimes referred to as the deviation or the error). A large error will generate a large output. The output signal is normally represented as a percent of output for the PID Control Period (V5020). Thus a 25% output with a 2 second control period will turn the solid state relays on for ½ second and off for 1½ seconds.

Proportional Control action includes a gain adjustment. The amount of gain determines the amount of output produced for a given error. For example, a gain setting of 10 will produce a 50% change in output for a 5% change in temperature (here temperature is expressed as a percent of range such that 100% is 3276.7 degrees).

The highest gain settings approach on-off control. Too much gain may result in an unstable or oscillating temperature. Too little gain results in a sustained error called offset.

Integral Control

Integral Control action is dependent upon time. It responds over time to the offset inherent in the proportional only controller. It will accommodate SetPoint and load changes by continuing to adjust the output until the error is eliminated. The actual response of the integral action depends on the setting of the reset adjustment.

The integral and proportional actions combine to force the temperature to the SetPoint. This is sometimes referred to as automatic reset.

Derivative Control

Even though proportional plus integral action eliminates offset, it may cause temperature overshoot. Derivative Control action is used to overcome excessive temperature overshoot. It is used only in combination with the proportional and integral control actions. Derivative Control action responds to the rate of change and direction of the error. The actual response of the integral action depends on the setting of the rate adjustment.

Traditional higher performance PID controllers include some form of derivative gain limiting. This is used when instabilities in the PV due to noise or other sources cause the output to become unstable. The FACTS Engineering Temperature Controller uses a proprietary Derivative Control action filter which de-glitches the PV while at the same time retaining the full effect of the rate setting. For correctly tuned loops, this method results in a lower damping ratio than a comparable controller with derivative gain limiting.

LOOP OPERATING MODES

The Temperature Controller operates in one of two modes, either PID or ON/OFF control.

PID Control

In PID Control mode, the Temperature Controller initially computes and controls the outputs based on the programmed PID parameters stored in V-Memory. These parameters are normally calculated during the Auto Tuning process. All alarms limits are continually monitored.

ON/OFF Control

In ON/OFF Control mode, the Temperature Controller outputs turn on and off based on only the Process Temperature, Set Point, ON/OFF Hysteresis, and control type either heating or cooling.

LOOP ALGORITHM

This section describes the PID algorithm used by the Temperature Controller.

Loop Variables

All loop calculations are performed using normalized Reals. A normalized Real is a floating point number in the range of 0.0 to 1.0. High precision is maintained since the floating point calculation is carried out to eight significant digits. The output from the loop is converted from a normalized Real to either a 12-bit number, 0-4095, or the amount of output 0-100.0%.

PID Control

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

Let

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

Then

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

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

PID equation

The Temperature Controller approximates the output M(t) using a discrete 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 (temperature) at nth sample.
e_n = SP - PVn = Error at nth sample.
M_O = Value to which the controller output has been initialized

Then

M_n = Controller output at nth sample.

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

The Temperature Controller 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 Temperature Controller 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:

Mx0 = M0

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

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

The Temperature Controller 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.

Reverse Acting Loop (Cooling)

The Temperature Controller 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.

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

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

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 heater and the temperature 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 turning off the heater. However, since the error term is still negative, the bias will continue to decrease becoming ever more negative. When the temperature finally does come back down below the SP, the heater will stay off until the error is positive for long enough to cause the bias to become positive again. This will cause the controller to overshoot the SetPoint.

One way to solve the problem is to simply clamp the bias between limits. The Temperature Controller does this. However, if this is the only thing that is done then the output will not move off 0.0 (thus turning on the heater) until the temperature has become less than the SetPoint. This will also cause the controller to undershoot.

The Temperature Controller solves the overshoot problem by freezing the bias term.

Freeze Bias

Freeze Bias means the Temperature Controller simply stops changing the bias (Mx) whenever the computed normalized output (M) goes outside the interval 0.0 to 1.0.

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

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

$M_n = 0$ if $M < 0$
$M_n = M$ if $0 \leq M \leq 1$
$M_n = 1$ if $M > 1$

$Mx_n = Mx$ if $0 \leq M \leq 1$
$Mx_n = Mx_{n-1}$ otherwise

Thus in our example, the bias will probably not go all the way to zero so that, when the temperature does begin to come down, the loop will begin to turn on the heater 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.

APPENDIX B: TROUBLESHOOTING

If the module is not operating as expected then use this appendix to get the module up and running quickly.

First review the description of normal module operation. If this does not identify the problem then scan the following frequently asked questions plus solutions to common problems. If you are having trouble with auto tuning a loop then please see the separate Auto Tune Troubleshooting section beginning on page 4.2.

Description of Normal Operation

At power up the OK LED comes ON and the module logs into the I/O configuration as a D4-DCM intelligent CoProcessor module.

The RUN LED starts flashing at a rate of ON for one second OFF for one second.

The value of zero is written to the slot dependent Error Flag Location (error codes can be found on page 2.10).

The firmware version is written to the slot dependent Version location (slot dependent V-Memory addresses can be found on page 2.8).

The Output, Auto Tuning, Heater Burn-Out, and Alarm LEDs come ON as appropriate to the current conditions of the enabled temperature loops.

Bit 15 of the Alarm Word for each enabled temperature loop is toggling.

The output for each enabled temperature loop is being controlled correctly.

Common Loop Temperature Controller Problems and Solutions

Problem:	TB and 24V LEDs are flashing back and forth.
Cause:	There is a configuration error in the slot dependent V-Memory locations. The slot dependent V-Memory location containing the Error Flag will tell you what the error is. Usually an invalid Table Beginning Address or invalid Number of Loops Enabled causes this error.
Solution:	Correct the ladder that initialized these values or write the correct values with your programming or host software and power cycle the module.

Problem:	The built-in SSR Output is not coming on when the Temperature Output is non-zero.
Cause:	The SSR output may be disabled because bit 15 of the Mode Word is ON.
Solution:	Turn off bit 14 of the Mode Word.

Problem: The temperature always reads 3276.7 degrees.

Cause 1: The module is not jumpered correctly for the type of input device. See page 2.2 for module jumper settings.

Solution 1: Jumper the module correctly.

Cause 2: The Input Type location does not have the correct code for the type of input device that is connected. See page 2.19 for the valid input types.

Solution 2: Set the Input Type location to the correct code for your input device.

Cause 3: The temperature input device is wired incorrectly or it is defective.

Solution 3: Check your wiring or try another field device.

Problem: The temperature reading is way off from what I expect.

Cause 1: The Temperature Units bit in the Mode Word is not set for the type of temperature indication desired. Bit 2 of the Mode Word selects the temperature units (0=oF, 1=oC).

Solution 1: Set bit 2 of the Mode Word appropriately for your application.

Cause 2: The BCD/HEX data type is being used to view the temperature loop parameters instead of the Decimal data type.

Solution 2: Use the Decimal data type to view the temperature loop parameters.

Cause 3: The temperature is negative and the sign-bit is not being taken into consideration. If a temperature is negative it will be displayed as a decimal number greater than 32767. You can subtract 32768 to get the absolute value of the temperature. A decimal value of 38634 indicates -586.6 degrees.

Solution3: Take the sign-bit into consideration when viewing the temperature.

Cause 4: Tenths of a degree are not taken into account. A decimal value of 1435 indicates 143.5 degrees.

Solution 4: Take tenths of a degree into account when viewing the temperature.

Problem: The Temperature Deviation Alarm does not come on when the current temperature is outside the value specified by the Temperature Deviation Alarm.

Cause 1: The Temperature Deviation Alarm is not enabled in the Mode Word.

Solution 1: Turn ON Bit 5 of the Mode Word to enable the Temperature Deviation Alarm.

Cause 2: The deadband is not being taken into account. If the deadband value is non-zero then that value is added onto the Temperature Deviation Alarm value.

Solution 2: Take the deadband into account with all alarm limits.

Problem: I changed the loop starting address or the number of loops but the module still seems to be using the old values.

Cause: These values are only read when module powers up.

Solution: Power cycle the module.

Problem: I changed my alarm parameters but the new values don't seem to be used.

Cause: These values are only read when bit 0 of the Mode Word is set.

Solution: Set bit 0 of the Mode Word (see the example on page 3.1).

Problem: I changed my PID loop parameters but the new values don't seem to be used.

Cause: These values are only read when bit 0 of the Mode Word is set.

Solution: Set bit 0 of the Mode Word (see the example on page 3.1).

If you have any installation or operation questions, or if you need additional information, please call 1-800-633-0405.

To receive the fastest help from our technical support staff, please have the following Temperature Controller information ready when you call:

- Value in the Table Beginning Address location (page 2.8).
- Value in the Number of Loops Enabled location (page 2.8).
- Value in the Error Flag location (page 2.8).
- Value in the Firmware version number location (page 2.8).
- Jumper Settings (page 2.2)
- Current value of all 19 V-Memory locations associated with the loop you are now having problems with (page 2.12).