Conic Systems Inc.

INSTRUCTION MANUAL
FOR
DATATRAN
C2844
PID CONTROLLER
WITH
FEED FORWARD
COMPENSATION

FOR TECHNICAL OR SALES ASSISTANCE
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GENERAL DESCRIPTION:

This PID controller module is designed to provide the experienced user with all of the functions required to implement a complete high performance, closed loop, three mode (proportional, integral and derivative (PID)) control system on a single circuit board. In addition to the standard PID functions, the board contains feedforward as well as external bias and signal scaling circuits. All of the function blocks feature compatible signal levels, thus allowing them to be directly interconnected to produce the configuration required for a specific application. The module features are described below.

- Operation directly from the AC power line or from a unregulated, bipolar, DC power supply.
- Transducer power supply, providing regulated positive and negative DC output voltages that may be used to power the external system transducers.
- Bipolar, PID amplifier section with independently adjustable gain, integration rate and derivative controls. Any combination of the proportional, integral and derivative functions can be selected by the board mounted jumpers. Each gain block function can be set independent of the others, the three signals are combined at the output with the bias and feedforward signals to produce to final signal to the process control element.
- Internal or external input signals for the integral section. The result of the integration operation is summed with the proportional gain and the derivative signals. The integral signal is automatically adjusted to limit the sum of the three signals to the boards rated output voltage value.
- Output signal voltage clamps. Both the positive and negative output signal can be clamped to values less than the rated maximum. The positive and negative clamps operate independently. The clamps operate on the internal integration circuit so that any input signals that would force the output beyond the clamp setting are automatically compensated for with a corresponding change in the integration section output.
- Provisions for integral reset and inhibit via external contact closure.
- Feed forward compensation section to provide the fastest possible response to dynamic changes in the input signal. The feedforward signal is summed with the PID signal at the output and will not effect the static PID tuning.
- Internal bias or zero adjustment control that may be used to eliminated system offsets or deadband in the control element.
- External bias input signal that is summed with the PID signal at the output with a gain of one.
- Two separate signal scaling amplifiers, each with adjustable gain and bias. These amplifiers can be used to convert voltage or 4 to 20 ma. current input signals to levels that are suitable for additional processing by the other functions on the PID controller module. The signal scaling amplifiers provide jumper selected inverted or non inverted outputs.
- Difference amplifier section that provides an output that is the result of subtraction of one input signal from another. This section can also be used as a inverting or non-inverting buffer with a gain of one. Optionally, this amplifier can be supplied with fixed gains of 5 or 10. These higher gains allow the difference amplifier to act as the summing input for load cells arranged in a full bridge configuration.
- Bipolar output amplifier with adjustable positive and negative maximum output voltage clamps.
- The PID section operates with command and feedback signals of the same polarity.
- Test points for error signal magnitude and integrator output monitoring, on the board.

The PID controller module is supplied as a single, industrial grade, circuit board assembly. All of the common user adjustment controls are made with multiple turn potentiometers. The operating mode is selected via multiple position pin headers with shorting bars, thus the board can be reconfigured for any changes in the control application without the need to solder or remove any components. All external power and signal wiring connections to the board are made to plug in terminal blocks. All of the external connections to the terminal blocks as well as the adjustment controls are clearly marked on the board.

INSTALLATION INSTRUCTIONS::

Once the circuit board assembly has been removed from the shipping container, inspect the unit to determine if any of the components have been or damaged during shipment and storage. In the event that any items are damaged, missing or should loose parts be discovered, they must be repaired or replaced before proceeding with the installation.

In the event that the equipment is not to be used for a period of time it should be stored in the shipping carton. The storage area should be dry and protected. Severe humidity or temperature, vibration and dirt are adverse conditions that can be injurious to the equipment and must be avoided.

The location selected for mounting the equipment should be of the same nature as that selected for storage. The temperature should be such that the ambient does not rise above 55 degrees C. Note, that 55 degrees C. is the maximum ambient surrounding the devices on the circuit board when it is operating at maximum load with the maximum rated input voltage applied. Due to the voltage regulator heat dissipation in this condition, it may be necessary to force some cooling air through the equipment if the plant temperature approaches 55 degrees C. In the event that forced air cooling is required, always install a good filter in the inlet stream ahead of the controller.

All of the ***electrical connections to the PID controller module must be made in strict conformance with the connection diagrams in this manual, as well as all applicable electrical codes*.** Should conflicts occur between the connection diagrams and the local electrical code, Datatran's engineering department should be consulted prior to proceeding with the installation.

It is recommended that the system common (0 volt line) be operated at earth ground potential. This will provide the highest immunity to any electrical noise as well as the maximum safety for the operator. The system common terminal is clearly marked on the board connection drawings included in this manual. This point should be run directly to the plant earth ground with a wire no smaller then that used to connect the power line to the equipment. Connections to the PID controller module should be in conduit separate from all other plant wiring for optimum performance and reliable operation in the high electrical noise environment typical in most industrial operations. This is particularly true for external command and feedback signal input lines.

Where shielded cable is called for on the connection diagram, expose the shield on the controller end only. If this cable is spliced at any point along its run be sure that the shield splice is covered and not grounded at any point along the run. Shielded cable should be in separate signal conduits only. They should not be run parallel to non signal conduits. If any signal conduits must cross non signal wires they should do so at an angle between 45 and 90 degrees.

The importance of proper wire routing during the installation period can not be overstated; all of the time spent on this operation is well worth it and will eliminate a number of potential problems and the associated expense that will occur to eliminate improper connections during the startup and operation of the equipment.

! ! ! ! ! WARNING ! ! ! ! !

The PID controller module is transformer isolated from the AC power line (AC line powered models only). The controller does not provide any additional signal isolation. It is extremely important that the entire control system have a single common or earth ground connection.

Multiple grounds or common connections that differ in electrical potential may cause high current flows resulting in fire and/or permanent damage to the controller as well as other devices connected to the system.

For operator safety all ungrounded equipment should be clearly marked as such.

THEORY OF OPERATION:

The three mode (proportional, integral and derivative) controller is by far the most widely used method of industrial control. The function of the controller is to set and maintain the physical process output exactly at the desired command value. Process functions that typically incorporate three mode control are speed, torque, flow, pressure, temperature and position.

In operation, the current state of the process is measured with a suitable transducer and compared to the input command signal. Any difference existing between the two signals is detected by the controller and a correction signal applied to the process control device in a manner that will tend to reduce the error to zero. A specific process may require a combination of the three modes available to produce satisfactory performance.

Proportional control alone adjusts it's output to be proportional to the error signal or the difference between the setpoint and the current value of the process variable. This difference is multiplied by the controller gain and applied to the process control device in a attempt to reduce this error to zero. Proportional control by definition requires that some error exist to generate any output. Thus, one of the characteristics of proportional control alone, is inherent offset from the setpoint. This offset can be reduced by increasing the system gain, however their are limits to this solution as eventually the system will become unstable. The amount of offset will vary as the setpoint or the nature of the process variable changes. Offset can be eliminated entirely with the addition of integral control.

Integral control, sometimes referred to as reset action, can be added to eliminate the offset generated by the proportional mode. This is a time dependent output, driven by the error signal. As long as any difference exists between the setpoint and the process feedback signal the controller will output a corrective signal. This corrective action is obtained by summing the error signal over time (integration). Once the controller error signal reaches zero, the integration process will stop. The output signal will stabilize at the current integral value.

The integration function acts the same as a manual shift in the command setpoint or the addition of a bias signal to bring the process variable to it's desired value. In operations where the process variable is slow responding or unable to reach the correct value, the integral term will tend to grow until the output control device is at its limit, either full on or off. At this time, any remaining error will cause the controller output to increase beyond the point where any additional control action can take place. This situation is referred to as integral windup and should it occur, control of the process will be lost. The process response must then reach the other side of the setpoint to reverse the integral term before control can be regained. Unfortunately, this action, combined with the proportional gain signal will force the controlled device to overshoot the setpoint. Integral windup generally causes problems with processes that are subject to frequent starts and stops or must operate at very low proportional gain settings.

Integral windup can be prevented by halting the integration signal when the combined proportional and integral signals cause the controller output to reach it's rated output signal limit. This action is called integral clamping. The PID controller module includes provisions to automatically adjust the integral signal to limit the output to the controller's rated value and prevent integral windup.

Proportional plus integral control (PI) will provide a fast response with zero offset, however the integral term tends to reduce stability and to cause overshoots on startup or setpoint changes. This overshoot or ringing can be reduced or eliminated with the addition of the derivative signal or rate control mode.

Derivative control monitors the rate of change in the process variable and tends to reduce the controller output in direct proportion to this rate. Thus, the derivative function acts as a brake to reduce overshoot and ringing of the process variable. Derivative control is never used alone as it's steady state output will always be zero. The PID controller module derivative signal is obtained from the process variable only and then summed with the proportional gain and integration value signals.

When the derivative signal is derived from the process variable only, setpoint changes are not affected by the derivative action, resulting in a smoother transition of the output. In addition, when the system is correctly tuned, the integrator action is reduced by the derivative action, thus the process will approach the setpoint smoothly with a minimum of overshoot.

Proportional plus integral plus derivative control (PID) will provide a fast response, zero offset and minimum overshoot or ringing of the controlled process. This is the preferred mode of operation in most process control applications.

The PID controller module also includes feed forward compensation. This function will detect rapid changes

THEORY OF OPERATION, CON'T:

of the feedforward signal and apply a corrective action to the output independent of the PID signals. This function is arranged so that a rapid drop of it's input signal will cause a momentary increase in the controller output. The feedforward compensation anticipates a need for a output signal change, thus it's action is similar to the derivative action but in the opposite direction. Feedforward is typically used in systems where the output of the process control element will vary from the action of something besides the control signal from the PID module.

Like the derivative function, feed forward compensation is never used alone, it's steady state output is zero. Feed forward compensation tends to reduce system stability. It should only used when transient changes of the input signal must be detected and applied to the output prior to the PID loop response. Feed forward compensation will add accuracy to systems that are subject to rapidly changing input signals.

A summation of the various PID controller module functions is outlined in the table below:

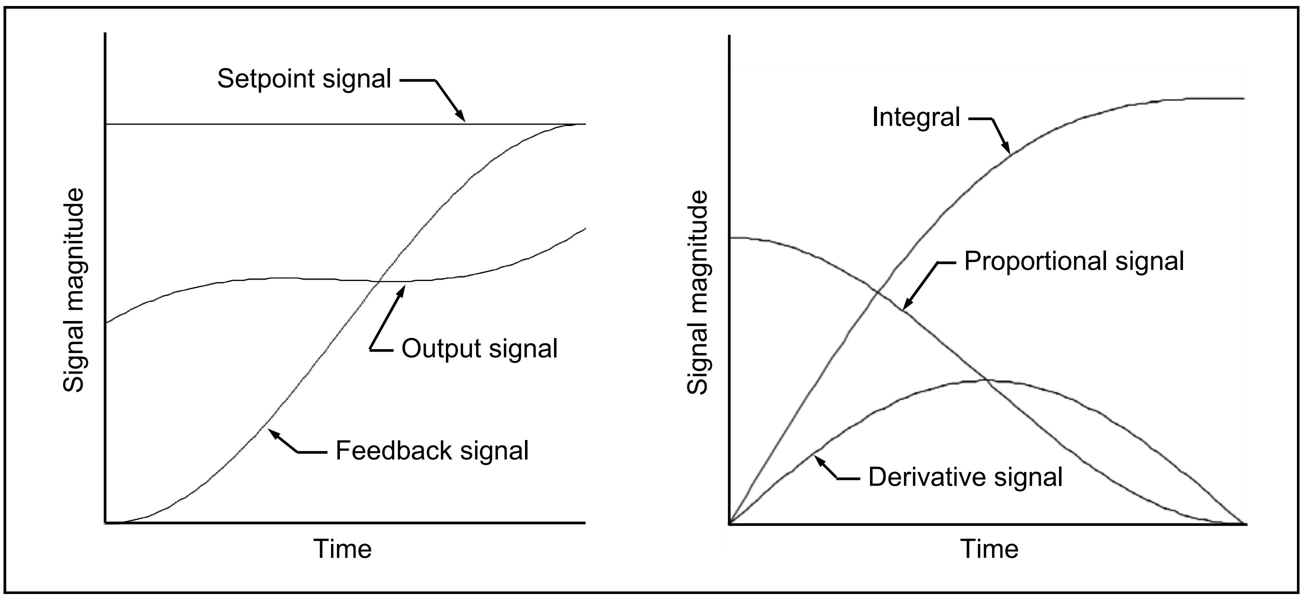
CONTROLLER MODE	ADVANTAGES	DISADVANTAGES
Proportional	Fast response, easy to tune	Inherent offset, large overshoots
Integral	Removes offset, zero steady state error	Slow reacting, integral windup
Derivative	Reduces overshoot, improves stability	No steady state action
Feedforward	Increases response, better regulation	Hard to tune, decreases stability

CONTROLLER RESPONSE:

When the controller is operated with all three modes (PID) enabled the output signal at any time can be expressed as shown in the equation below.

$$\text{Controller output} = (kp * \text{error}) + (ki \int \text{error}) - (kd * d(\text{feedback})/dt)$$

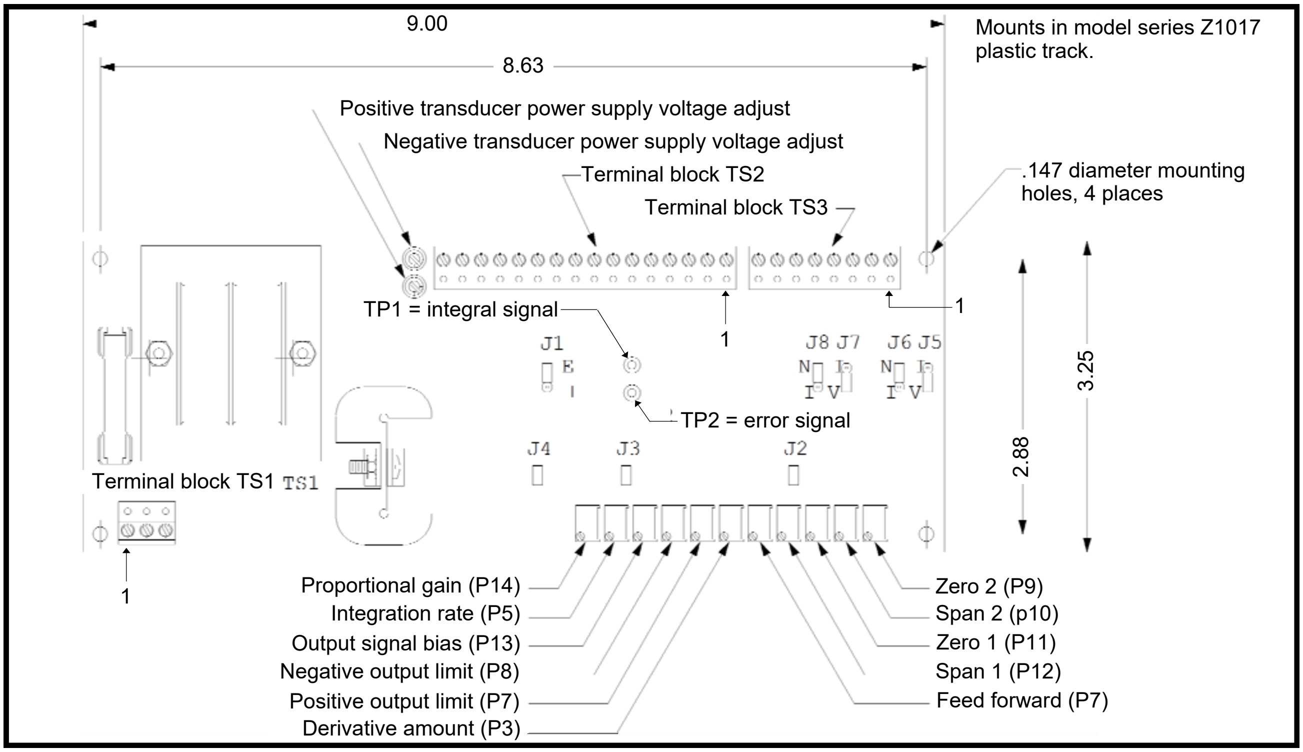
Where kp, ki and kd are the proportional, integral and derivative gain settings. The term "error" is equal to the setpoint value minus the feedback signal.



The graphs in the figure above illustrate the relationship between the controller signals in response to a step change in the setpoint value. In this example, the controller is tuned to produce a smooth response with zero overshoot.

The signals shown are derived with a step change in the setpoint and a sinusoidal response from the process. These signals will vary as a function of the tuning and the response generated for a specific application. They should be used for reference only.

OUTLINE DIMENSIONS AND COMPONENT LOCATIONS:



EXTERNAL WIRING REQUIREMENTS:

All external wiring shall be located in conduit or raceways. All shielded wiring must be located in it's own separate signal conduit. In general, all shielded wire should have the shield exposed and connected on one end only, as shown on the interconnection drawings. All of the wiring connections to the PID controller circuit board can be made with 20 AWG or larger. All command input and feedback wiring should be twisted and shielded.

All external non-shielded wires should be of stranded copper with thermoplastic (PVC) insulation, rated for 600 volts and 90 degrees C. minimum. All external, multiconductor shielded cables should be of stranded copper with a foil shield and thermoplastic (PVC) insulation, rated for a minimum of 300 volts at 80 degrees C. The wire and cable ratings listed are the minimum. The user is expected to show a bit of common sense in the selection of the external interconnection wires, the voltage rating, current capacity and operating temperature must be suitable for the specific application. ***All wires must be selected and installed as specified in the local electrical and fire codes.***

POWER LINE FUSE REQUIREMENTS:

All of the signal outputs will withstand a direct short circuit to the system common or the transducer power supply outputs. The transducer power supply voltage regulators are both short circuit and thermally protected.

All 115 volt or 230 volt AC power line input models (suffix AAA =111 or 231) are supplied with a fuse located in series with the connection to terminal number 1 on TS1. This fuse is rated for .5 amps for 115 volt models and for .3 amps for 230 volt models. Both fuses are specified at 250 volts. In the event that terminal number 2 on TS1 is not connected to the system earth ground, the user must install a fuse in series with this connection, equal in size to the internal fuse mounted on the board in series with terminal number 1. All external fuses should be equal to the Littelfuse series 312 (type 3AG, at 250 volts).

All models that are setup to operate with a DC power supply input *do not include the internal fuse*. In this case the power line connections to terminal number 1 and 3, on TS1 should be protected by a fast blowing fuse in series with each wire. Fuses should be no larger then .5 amp. These fuses should be equal to a Littelfuse part number 312.500 (type 3AG, rated 1/2 amp at 250 volts.

Do not install fuses in any conductor that is connected to the system earth ground.

The user should note that on DC powered models, a blown fuse in one of the input power line connections may cause the PID controller module output signal lines to assume a maximum positive or negative state.

USER ADJUSTMENTS:

The devices listed below are multiple turn potentiometers, located on the circuit board. These are the controls that are normally adjusted by the user to obtain the response required for a specific installation. The location of these controls is marked on the circuit board as well as the installation drawing on page number 5 of this manual.

OUTPUT SIGNAL BIAS (P13): Adjusts the magnitude of the controller output signal when all of the input signals are set to zero. The integration inhibit signal should be applied (jumper terminal number 9 to terminal number 10, on TS2) when adjusting this control. Clockwise rotation will produce a positive output voltage.

PROPORTIONAL GAIN (P14): Adjusts the magnitude of the controller output signal due to the proportional gain section output for a given amount of steady state error signal. Clockwise rotation increases the proportional signal gain. With this control set fully c'clockwise, the output from the proportional gain section will be zero.

INTEGRATION RATE (P5): Adjusts the magnitude of the controller output signal due to the integrator section output for a given amount of steady state error signal over a specific time period. Clockwise rotation will increase the rate at which the output changes.

DERIVATIVE AMOUNT (P3): Adjusts the magnitude of the controller output signal due to the derivative section output for a specific rate of change of the process feedback signal. Clockwise rotation increases the amount of applied derivative signal.

FEED FORWARD AMOUNT: (P4): Adjusts the amount that the output signal will change for a given rate change in the feed forward compensation input signal. A negative going input signal will increase the output in a positive direction. Clockwise rotation increases the amount of feed forward signal. With this control set fully c'clockwise the feed forward compensation signal is inhibited.

POSITIVE OUTPUT LIMIT (P7): Sets the magnitude of the maximum positive output voltage that can be produced by the PID signals. Clockwise rotation will increase the output.

NEGATIVE OUTPUT LIMIT (P8): Set the magnitude of the maximum negative output voltage that can be produced by the PID signals. Clockwise rotation will increase the output.

ZERO 1 ADJUST (P11): Adjusts the magnitude of the auxiliary output number 1 signal when the input signal at terminal number 7 on TS3 is set to it's minimum value. Clockwise rotation will produce a negative output voltage with the "N-I" jumper, J8 set to the "N" position.

SPAN 1 ADJUST (P12): Adjusts the magnitude of the auxiliary output number 1 signal when the input signal at terminal number 7 on TS3 set to it's maximum value. Clockwise rotation will increase the output signal.

ZERO 2 ADJUST (P9): Adjusts the magnitude of the auxiliary output number 1 signal when the input signal at terminal number 5 on TS3 is set to it's minimum value. Clockwise rotation will produce a negative output voltage with the "N-I" jumper, J6 set to the "N" position.

SPAN 2 ADJUST (P10): Adjusts the magnitude of the auxiliary output number 1 signal when the input signal at terminal number 5 on TS3 set to it's maximum value. Clockwise rotation will increase the output signal.

SUPPLEMENTARY ADJUSTMENTS:

The devices listed below are single turn potentiometers that are located on the circuit board. They are preset and sealed at the factory prior to shipment. They do not normally require additional adjustment by the user. The function of these devices is included for reference only. The location of these devices is marked on the installation drawing on page number 5 of this manual.

POSITIVE TRANSDUCER SUPPLY: Adjusts the magnitude of the positive output voltage for the transducer power supply.

NEGATIVE TRANSDUCER SUPPLY: Adjusts the magnitude of the negative output voltage for the transducer power supply.

POSITIVE REFERENCE SUPPLY: Adjusts the magnitude of the internal positive voltage power supply. *User adjustment of this device may render the PID controller inoperative.*

NEGATIVE REFERENCE SUPPLY: Adjusts the magnitude of the internal negative voltage power supply. *User adjustment of this device may render the PID controller inoperative.*

OPTION SELECT JUMPERS:

These are multiple position pin headers that are located on the circuit board. They should be positioned by the user, prior to installation, to set the mode of operation required for a specific application. The location of these jumpers is marked on the circuit board as well as the installation drawing on page number 5 of this manual.

INTEGRATOR SIGNAL SOURCE (J1): Selects the input source for the signal applied to the integrator section. With this jumper in the "E" position the input signal will be obtained from terminal number 11 on TS2. In the "I" position the input signal will be the internal error voltage.

INTEGRATOR CLAMP SELECT (J2): Controls the integration windup mode. With this jumper installed, the output of the proportional gain section combined with the output from the integrator and derivative sections will be clamped to the values set by the Positive and Negative Limit controls. With this jumper removed, the output from the integrator is not clamped and will increase as long as any error signal exists until the amplifier is saturated.

INTEGRATOR MODE (J3): With this jumper installed the output from the integrator section is summed with the outputs from the proportional gain and derivative sections. With this jumper removed, the integration function is disabled.

DERIVATIVE MODE (J4): With this jumper installed the output from the derivative section is summed with the outputs from the proportional gain and integration sections. With this jumper removed, the derivative function is disabled.

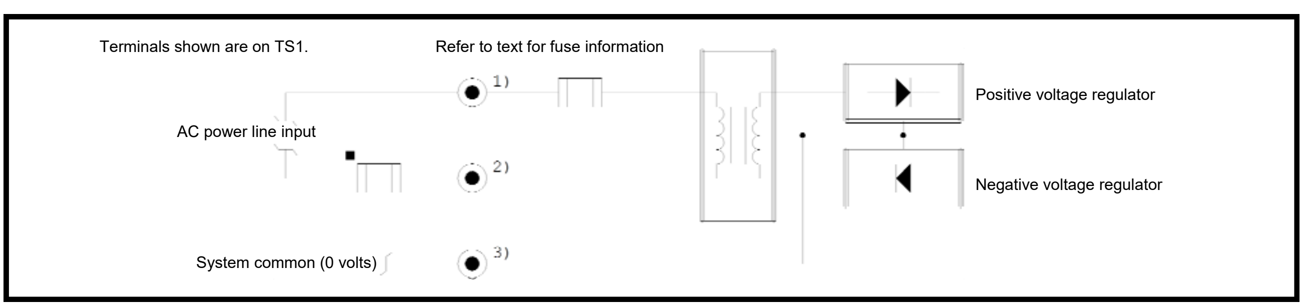
AUXILIARY INPUT 2 MODE (J5): Selects either voltage or 4 to 20 ma. current input signals for auxiliary input number 1. In the "V" position the input is a voltage signal. In the "I" position the input signal should be from a 4 to 20 ma. current source. Input signals are applied to terminal number 5 on TS3.

AUXILIARY OUTPUT 2 MODE (J6): Selects either inverted or non-inverted operation. In the "N" position the output voltage signal will be of the same polarity as the input. In the "I" position, the output will be opposite in polarity of the input. The output voltage signal appears on terminal number 6 on TS3.

AUXILIARY INPUT 1 MODE (J7): Selects either voltage or 4 to 20 ma. current input signals for auxiliary input number 1. In the "V" position the input is a voltage signal. In the "I" position the input signal should be from a 4 to 20 ma. current source. Input signals are applied to terminal number 7 on TS3.

AUXILIARY OUTPUT 1 MODE (J8): Selects either inverted or non-inverted operation. In the "N" position the output voltage signal will be of the same polarity as the input. In the "I" position, the output will be opposite in polarity of the input. The output voltage signal appears on terminal number 8 on TS3.

EXTERNAL POWER SUPPLY CONNECTIONS, AC INPUT MODELS

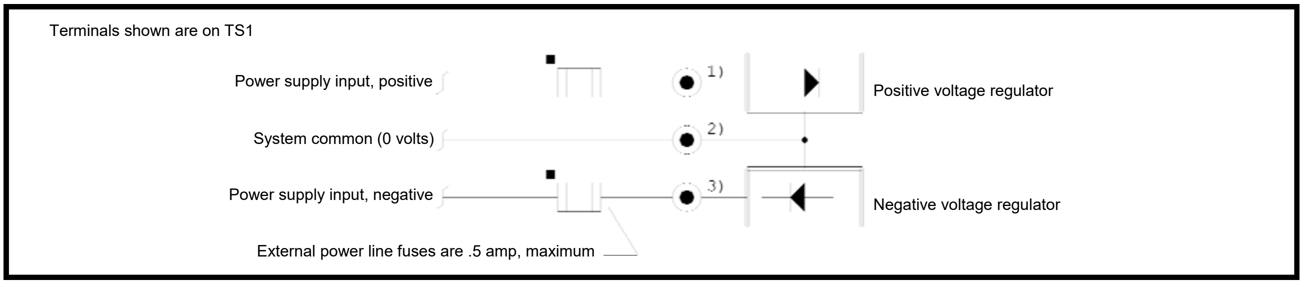


The external fuse shown in series with the connection to terminal number 2 on TS1 should *not be installed* if this line is connected to the system earth ground. The external fuse should be the same size as the factory supplied internal fuse in series with the connection to terminal number 1 on TS1.

The nominal input voltage for controllers with suffix AAA = 111 is 115 volts AC. The nominal input voltage for controllers with suffix AAA = 231 is 230 volts AC.

The factory supplied fuse will be rated at .5 amps for 115 volt AC input models and .3 amps for 230 volt AC input models. All fuses should withstand 250 volts rms.

EXTERNAL POWER SUPPLY CONNECTIONS, DC INPUT MODELS:



The fuses shown in the connections to terminal numbers 1 and 3 on TS1 are not required if the user's external power supply includes the necessary short circuit protection devices.

Do not install fuses in any conductor that is connected to the system earth ground.

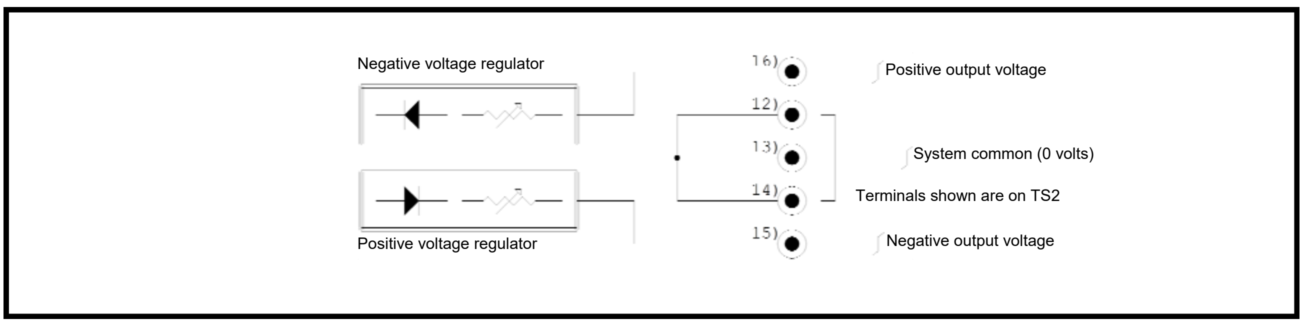
The external fuses should be rated at .5 amps for all DC voltage powered models.

The minimum input voltage for controllers with suffix AAA = 100 is plus and minus 10 volts DC. The minimum input voltage with suffix AAA = 150 is plus and minus 15 volts DC. The maximum input voltage to all DC powered controllers is plus and minus 30 volts DC.

! ! ! ! ! CAUTION ! ! ! ! !

Improper connection of the input power line voltage selection jumpers may cause irreparable damage to the PID controller circuit board assembly.

TRANSDUCER POWER SUPPLY CONNECTIONS:



The transducer power supply output current is limited by the regulators ability to dissipate heat as well as the maximum power rating for the transformer on AC line powered models. The maximum output current at all ambient temperatures can be determined from the formula given below:

$$\text{Maximum current (amps)} = \frac{125 - \text{Ambient temperature (degrees C.)}}{19.4 * (\text{Supply voltage} - \text{Transducer}}$$

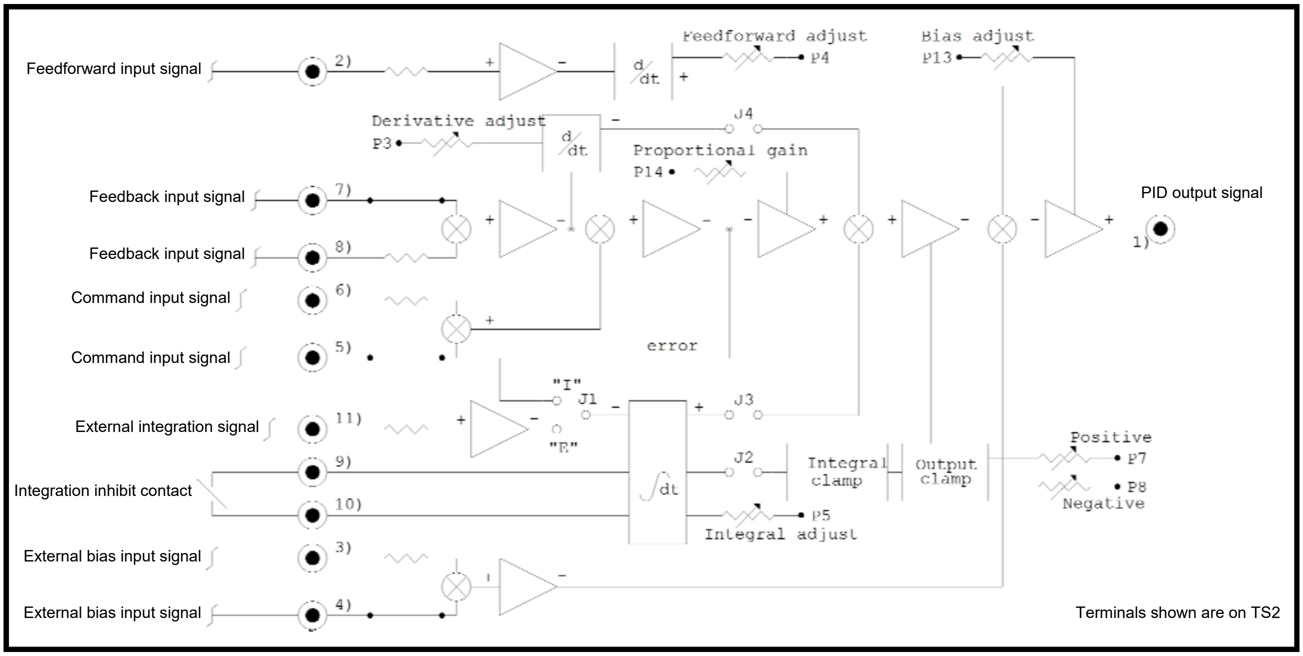
In order to prevent damage to the voltage regulators or transformer secondary windings, the maximum continuous current drawn from either output should not exceed .2 amps under any load or temperature condition.

When using the formula above to calculate the maximum current that can be delivered by the transducer power supply, the supply voltage value inserted for all AC line powered models is 30 volts. For DC powered models, use the maximum applied input power line voltage.

One additional note, the minimum differential voltage between the power supply inputs and the transducer outputs must be equal to 2.5 volts. The input voltage must also exceed the rated signal output voltage (defined by suffix CCC) by at least 2.5 volts. Failure to provide the voltage differentials specified may cause excessive ripple on the transducer supply lines as well as a limited or distorted signal swing at the outputs.

Note*: the formula above calculates the absolute maximum output current. The prudent user will limit the output current to lessor values to obtain maximum reliability from the equipment.*

PID AMPLIFIER, FEEDFORWARD AND EXTERNAL BIAS CONNECTIONS:



User signals applied to terminal numbers 4, 5 and 7 require that the user supply external resistance in series with these signals. The correct resistance value is determined by the maximum value of the input signal and the rated input of the controller. The required resistor value can be determined with the formula below.

$$\text{Resistor value (ohms)} = \frac{\text{Maximum input voltage * Scale output}}{5}$$

The number used for the scale value in the equation above is dependent upon the rated input of the controller, as defined by suffix BBB. The correct scale value can be obtained from the table below.

Suffix BBB = 030, use 165,000 Suffix BBB = 050, use 100,000 Suffix BBB = 100, use 49,900

The minimum power rating for the selected resistor can be determined from the formula below.

$$\text{Power rating (watts)} = \frac{(\text{Maximum input voltage})^2}{\text{Resistor value (ohms)}}$$

For best performance, the selected resistors should have a 1% tolerance and a temperature coefficient better than 100 ppm. Upon request, Datatran will supply the PID controller boards with the correct resistors for terminal numbers 4, 5 and 7 located on the board.

Input voltages applied *to terminal number 4, 5 or 7 without a series resistor will destroy the PID controller.*

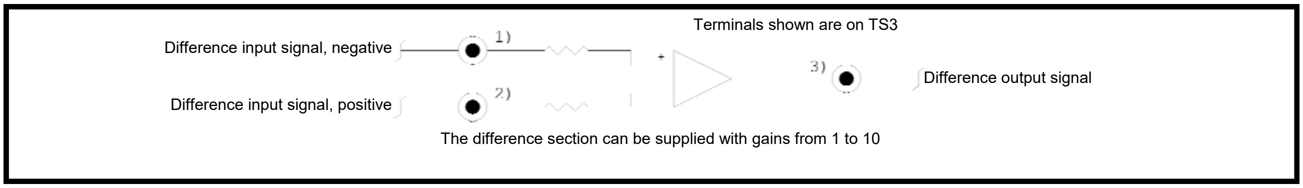
Input signals applied to the external bias terminal numbers 3 and 4 are scaled internally by the controller such that the maximum rated input voltage as determined by suffix BBB or the formula above, will produce the maximum rated output voltage on terminal number 1, as defined by suffix CCC.

In the event that no external signals are applied to terminal numbers 2, 3 or 11, these terminals should be connected to the system common. In the event that terminal numbers 4, 5 or 7 are not used, these terminals should be left unconnected. *Do not connect terminal numbers 4, 5 or 7 to the system common.*

The external integrator reset contact connected between terminal numbers 9 and 10 should be rated for low level switching. With this contact closed the integration function will be inhibited.

During the tuning process in can help to monitor the error and integration signals. The error voltage can be monitored at test point "TP2". The integrator output is available at "TP1". The error voltage measured at test point "TP2" will be opposite in polarity to the output signal. The integration voltage measured at test point "TP1" will be the same polarity as the output signal. In order to measure the integration voltage at test point "TP1", the integration mode jumper "J3" must be installed.

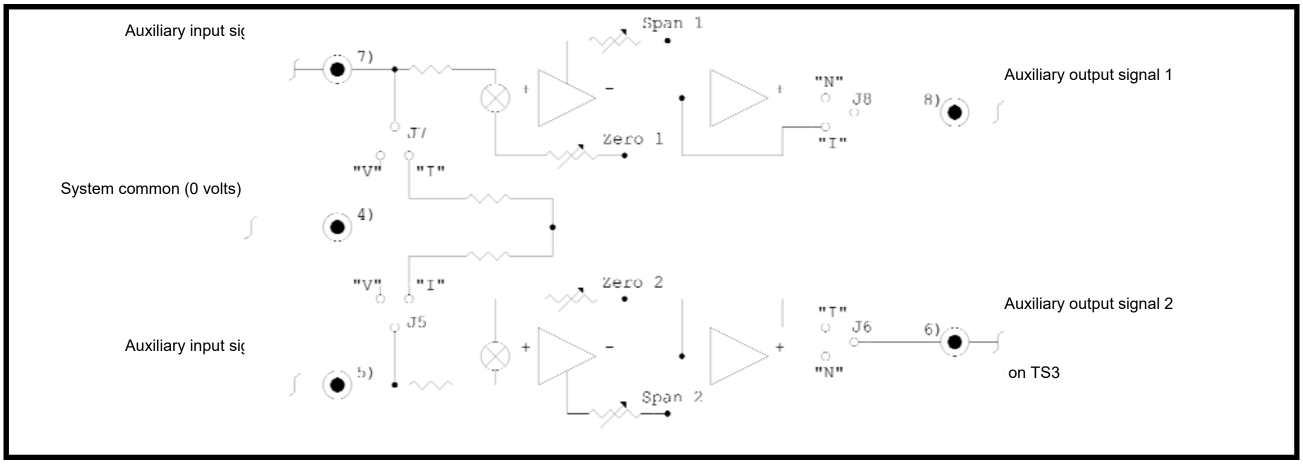
DIFFERENCE AMPLIFIER CONNECTIONS:



The output voltage from the difference amplifier section can be determined from the formula below

Output voltage = [Volts on terminal 1 – Volts on terminal 2] * Gain

SCALE SECTIONS 1 AND 2 CONNECTIONS:



Both of the scale sections will accept either voltage or current input signals. The type of input signal is determined by the position of jumpers "J5" and "J7". With either of these jumpers set to the "V" position, the input signal to the associated amplifier should be obtained from a voltage source. When the associated jumper is In the "I" position the input signal should be obtained from a current source.

Both the input current or voltage source must be referenced to the system common, terminal number 4 on TS3. Current input signals must source current into terminal numbers 5 or 7 on TS3.

When the scale section is used with a voltage input signal the output voltage can be determined from the formula below:

Output volts = [Input voltage signal + ZERO setting] * SPAN setting

SPAN adjustment range = .1 to 10.1 volts per volt.

When the scale section is used with a current input signal the output voltage can be determined from the formula below: Note that the amplifier input current signal is first converted to a voltage signal by passing it thru a 250 ohm resistor connected to the system common

SPAN adjustment range = .025 to 2.525 volts per ma.

$$\text{Output volts} = \left[\frac{\text{Input current signal (ma.) * 250}}{1000}\right] \text{* SPAN setting}$$

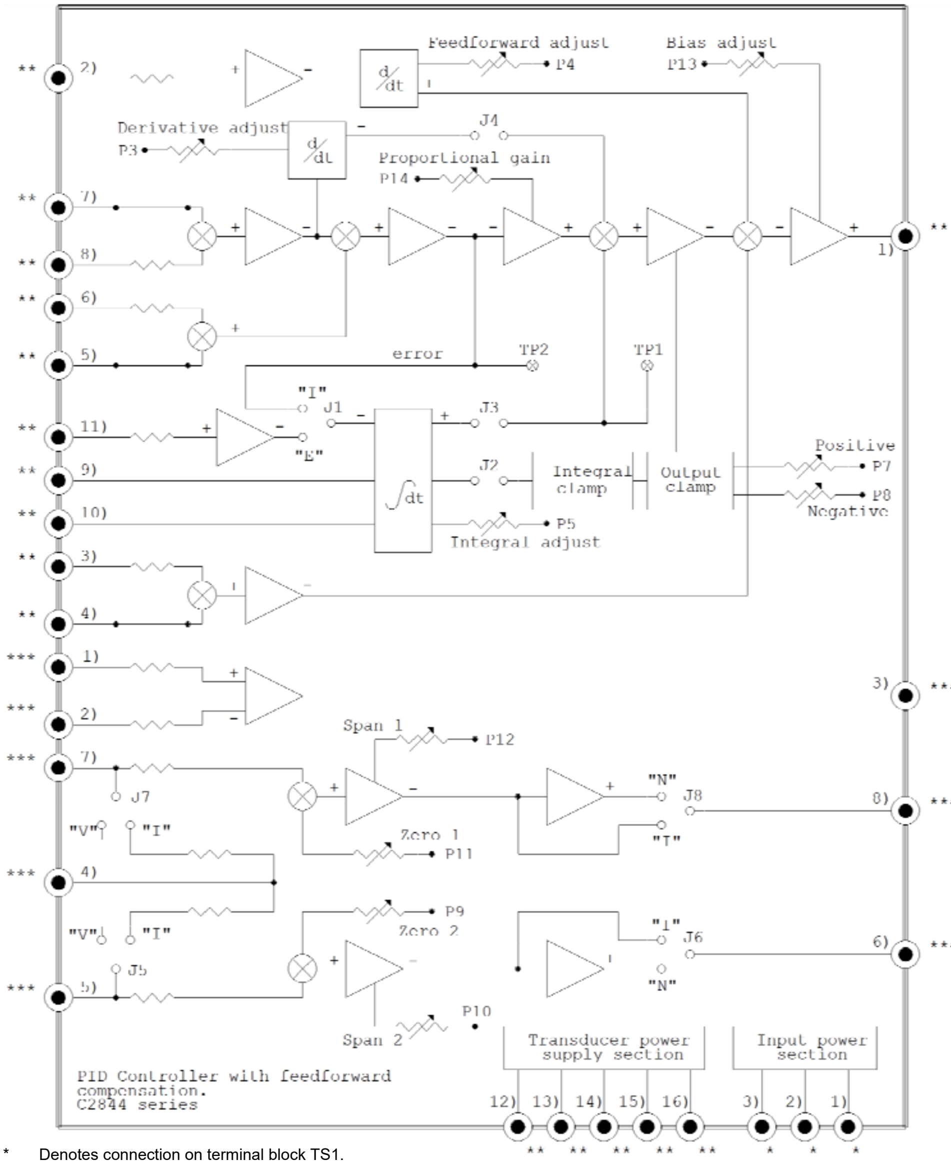
Alternately, the input current signal can be converted to it's equivalent voltage signal by use of the formula below and this value substituted in the formula given above for voltage input signals.

The 250 ohm scale section input resistor will convert 4 to 20 ma. inputs to 1 to 5 volts DC.

$$\text{Input voltage signal} = \left[\frac{\text{Input current signal (ma.) * 250}}{1000}\right]$$

For both current or voltage configurations the output voltage from the formulas given above must be multiplied by -1 (inverted) with jumpers "J6" or "J7" set to the "I" position.

FUNCTIONAL DIAGRAM



* Denotes connection on terminal block TS1.
** Denotes connection on terminal block TS2.
*** Denotes connection on terminal block TS3.

The functional drawing above shows the interconnection, signal polarities and function of the PID control and auxiliary modules supplied on the circuit board. The function and signals applied to each terminal are detailed in the chart on the next page of this manual.

The user should carefully examine the logic, signal flow and polarities shown on the functional diagram prior to installation. *Incorrect external wiring connections may damage the PID controller or produce unpredictable results when the controller is applied on a specific system*. User's with questions are encouraged to contact Datatran's technical support department. Our engineers will be pleased to help you select the correct configuration for you application. They can be reached by phone or FAX from 8:00 AM to 5:00 EST or EDT on Monday through Friday.

APPLICATION TIP:

The PID controller works very well when used as a tension control system with load cells to provide the feedback signal. The load cells should be connected in a full wave bridge configuration. The transducer should be connected to the positive transducer supply and the system common. The outputs from the bridge are connected to the inputs of the differential amplifier whose output is than connected to the scale section input. Zero, gain and signal polarity can be adjusted with the scale section controls. Upon request, Datatran can supply the board with a differential gain of 5 or 10.

EXTERNAL TERMINAL BLOCK CONNECTIONS:

Three terminal blocks are provided for the external user connections to the PID controller board. The terminals for power and signal wiring connections are separated in order to provide the maximum immunity to any induced electrical noise. The terminal blocks are removable to simplify any required maintenance and plug in to mating pins on the circuit board.

The terminal numbers on each block are numbered from 1, starting from the left most terminal when the block is viewed from the *wire entry side*. Terminal block locations as well as position number 1 for each block are shown in the figure on page 5. The function of each terminal is given in the tables below.

CONNECTIONS TO TERMINAL BLOCK TS1 (*), AC POWERED CONTROLLERS ONLY.	
TS1-1	Power line input, hot connection.
TS1-2	Power line input, neutral connection.
TS1-3	System common (0 volts), normally connected to the system earth ground.

CONNECTIONS TO TERMINAL BLOCK TS1 (*), DC POWERED CONTROLLERS ONLY.	
TS1-1	Power supply input, positive dc voltage.
TS1-2	System common (0 volts), normally connected to the system earth ground.
TS1-3	Power supply input, negative dc voltage.

CONNECTIONS TO TERMINAL BLOCK TS2 (**), ALL CONTROLLER MODELS.	
TS2-1	Main or PID section voltage signal output.
TS2-2	Feed forward compensation voltage signal input.
TS2-3	Primary external bias voltage signal input.
TS2-4	Secondary external bias voltage signal input. Requires external impedance in series.
TS2-5	Secondary command (setpoint) voltage signal input. Requires external impedance in series.
TS2-6	Primary command (setpoint) voltage signal input.
TS2-7	Secondary feedback (process variable) voltage signal input. Requires external impedance in series.
TS2-8	Primary feedback (process variable) voltage input signal.
TS2-9	Integration inhibit contact input. Connect TS2-9 to TS2-10 to inhibit the integration function.
TS2-10	Integration inhibit contact input.
TS2-11	External integration voltage signal input.
TS2-12	System common (0 volts) connection.
TS2-13	System common (0 volts) connection.
TS2-14	System common (0 volts) connection.
TS2-15	Transducer power supply, positive voltage output connection.
TS2-16	Transducer power supply, negative voltage output connection.

CONNECTIONS TO TERMINAL BLOCK TS3 (***), ALL CONTROLLER MODELS.	
TS3-1	Difference section voltage signal input, plus.
TS3-2	Difference section voltage signal input, minus.
TS3-3	Difference section voltage signal output.
TS3-4	System common (0 volts) connection.
TS3-5	Scale section 1, voltage (J7 = "V") or current (J7 = "I") signal input.
TS3-6	Scale section 1, voltage signal output, set the polarity with J8.
TS3-7	Scale section 2, voltage (J7 = "V") or current (J7 = "I") signal input.
TS3-8	Scale section 2, voltage signal output, set the polarity with J8.

! ! ! ! ! CAUTION ! ! ! ! !

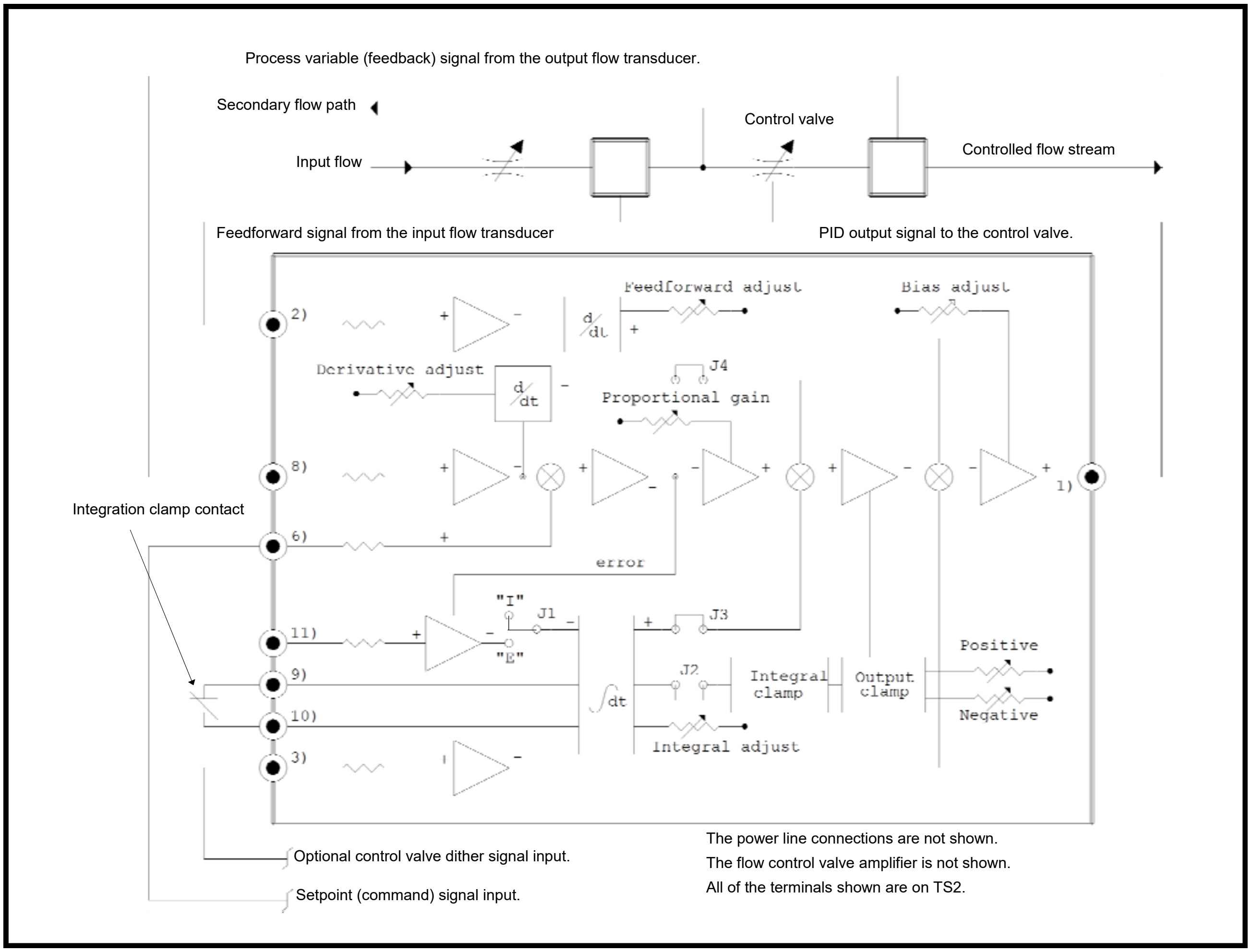
The PID controller module described in this instruction manual is designed to be applied by experienced user's on closed loop applications.

Although each individual component in a system may function perfectly by itself, once they are interconnected, closed loop operations can sometimes be difficult or in extreme cases impossible to stabilize.

The type of external load, it's location, the process control element gain as well as the system time constants and electrical noise all contribute to the stability considerations in any closed loop application.

Due to the numerous external factors acting upon the PID controller, Datatran is not able to guarantee that satisfactory operation can be obtained in all closed loop applications.

TYPICAL FLOW CONTROL APPLICATION:



Before we discuss the loop tuning for the typical application, illustrated above, we need to clarify a few things in order to define an acceptable, real world, control loop response. If we approach the tuning process with the assumption that we can set the loop to generate a perfect text book response, we should quit right now. It just can not be done with Datatran's or for that matter, anyone else's controller.

The perfectly tuned PID control loop will immediately respond to any changes in the setpoint or feedback signal without delay, overshoot or ringing and will always stabilize with a zero steady state error between the setpoint and the controlled variable. In theory, all physical processes can be mathematically described

TYPICAL FLOW CONTROL APPLICATION, CON'T:

by a series of differential equations, called the process model. Once you have a valid model, you run it thru your computer which in time will provide you with the correct values for the proportional gain, integration rate and derivative amount. You simply dial these calculated values into the controller, fire it up and go on to the next. Sounds good, however in the real world your carefully constructed model of the process is always going to be flawed. If you use the computer calculated PID values derived from a bad model, the process response can be exciting, to say the least.

All real world applications are subject to noise, delays, inertia, component tolerances and response times. These parameters vary over time and can't be predicted or modeled with any reasonable degree of accuracy over the life of the process. Accordingly, we can state that *the perfectly tuned PID loop is impossible to obtain.* Once we accept this fact we can modify our objective to try and tune the loop to produce a acceptable product (the output from the process). With this in mind, let us examine the control loop and then describe the tuning process for the application shown on the preceding page.

The application shown can reasonably described as any control engineers worst nightmare. The material being regulated is a compressive gas at very high flow rates. The input to the flow control valve will vary due to unpredictable demands made by the secondary flow loop. In addition, the flow control valve is subject to hysteresis and a slow response time. The positive things going for us in this application is the fact that both flow meters are very accurate as well as extremely fast acting and the setpoint range is limited. The tuning process for this application is more difficult than most, however, the tuning operation will provide the general guidelines that can be applied, by the experienced user, to other process control applications. The tuning process is described in the sections below.

CONTROL LOOP TUNING EXAMPLE:

In general, PID loop tuning should be approached as a black art as opposed to an exact science. What works for one application may be totally wrong for the next. Make small adjustments to one setting at a time and allow the loop to respond before proceeding with the next. Feel free to experiment, experience is the best teacher.

! ! ! ! ! WARNING ! ! ! ! !

The calibration instructions in this section are for use by qualified service personnel only. Line voltage will exist on the equipment at any time the power line is connected. To avoid possible injury or death do not attempt to calibrate or service this equipment unless you have been properly trained to do so.

Prior to starting the loop tuning process, take a look at the overall installation. For best results the mechanical components in the system should be correctly sized and interconnected. As a rule of thumb, the process control element and the feedback transducer should be sized so that with the process operating at 100% these devices are running at about 85% to 90% of their rated maximum. Signals for these devices should be as close as possible to those specified for the PID controller. Oversized devices act as if the controller gain has been increased, in extreme cases the mechanical gain of the loop may be so high that the loop can not be stabilized with the controller adjustments.. Another potential problem can be caused by control elements that are too slow. Phase shifts are induced into the loop when the process control element and the feedback transducer responses are too slow. These phase shifts tend to reduce the loop stability, they can generally be compensated for with the PID controller adjustments. However the overall loop response and accuracy required for stable operation may be so poor that acceptable control of the process is impossible. The importance of correct component selection and installation can not be overstressed.

1) Disconnect the feedback transducer signal wire from the PID controller. Manually operate the system and verify that the output signal from the feedback transducer is of the correct polarity and value. With the system stopped the feedback transducer output should be zero and at the maximum process output the feedback transducer should be of the same magnitude and polarity as the maximum setpoint command signal.

   The feedback transducer signal can be connected through one of the scale section amplifiers if adjustments are required. *The feedback signal values must be correct prior to proceeding with the PID* *loop tuning process.*

2) For the flow loop example shown, close off the secondary flow path and make sure that the input flow is adequate to produce the maximum controlled output flow..

3) With no input power applied, first turn all of the potentiometers on the circuit board c'clockwise twenty five (25) turns. Next, turn the "OUTPUT SIGNAL BIAS" (P13) control back clockwise approximately twelve (12) turns. Finally, turn the "POSITIVE OUTPUT LIMIT" (P7) and the "NEGATIVE OUTPUT LIMIT" (P8) controls back clockwise twenty five (25) turns.

4) Set the "INTEGRATOR SIGNAL SOURCE" (J1) jumper to the "I" position. Install the "INTEGRATION CLAMP SELECT" (J2), the "INTEGRATOR MODE" (J3) and the "DERIVATIVE MODE" (J4) jumpers.

5) Close the "INTEGRATION INHIBIT" contact or connect a jumper between terminal numbers 9 and 10 on TS2.

6) Disconnect the PID board output signal wire to the process control element (the flow control valve amplifier in our example). Set the input command signal to zero volts. Note, the feedback transducer wire was disconnected in step number 1, above.

7) Connect a DC voltmeter between terminal numbers 1 and 12 on TS2. Terminal number 12 is the system common or zero volt connection.

8) Apply power to the PID controller and adjust the "OUTPUT SIGNAL BIAS" (P13) control so that the voltmeter reads zero volts.

9) Set the input command signal to it's maximum positive voltage value. Turn the "PROPORTIONAL GAIN" (P14) control clockwise until the voltmeter reads approximately 110% of the maximum rated positive output signal.

10) Turn the "POSITIVE OUTPUT LIMIT" (P7) control c'clockwise until the voltmeter reading is equal to the maximum rated input of the process control element, the flow control valve amplifier in our example.

    If the input command signal is unipolar (as in our example), Turn the "NEGATIVE OUTPUT LIMIT" (P8) control back c'clockwise twenty five (25) turns , and proceed directly to step 13 below.

11) Set the input command signal to it's maximum negative voltage value. The voltmeter should indicate approximately 110% of the maximum rated negative output signal.

12) Turn the "NEGATIVE OUTPUT LIMIT" (P7) control c'clockwise until the voltmeter reads 100% of the required negative output signal.

13) Set the input command signal to zero. The voltmeter should read zero volts. Remove the input power from the controller.

14) Turn the "PROPORTIONAL GAIN" (P14) control back c'clockwise 25 turns.

15) Reconnect the PID controller output signal wire to the process control element (the flow control valve in the example). Reconnect the wires to the feedback transducer. Confirm that the secondary flow path is blocked and that the input flow is steady at a value that is capable of delivering maximum output to the controlled flow stream.

16) Apply the input power to the controller and adjust the "OUTPUT SIGNAL BIAS" (P13) until a small controlled flow is observed. At this point turn the "OUTPUT SIGNAL BIAS" control back until the controlled flow is zero.

17) Set the input command signal to approximately 75% of it's maximum value. Verify that the input flow is at a stable value.

18) Slowly, adjust the "PROPORTIONAL GAIN" (P14) control clockwise until the controller output just starts to oscillate. The output from the controller can be observed on the voltmeter.

    This is a flow loop with a slow acting controller, experience has shown the system will require a very low proportional gain setting for stability.

19) Slowly, adjust the "DERIVATIVE AMOUNT (P3) control clockwise until the controller output is stable. If the controller output can not be made stable with the "DERIVATIVE AMOUNT" control, set the "DERIVATIVE AMOUNT" for the least amount of instability.

    Experience has shown that systems with large inertia loads or slow acting control elements will require quite a bit of derivative for stability.

20) Slowly, adjust the "PROPORTIONAL GAIN" (P14) control clockwise until the controller output just starts

to oscillate. Than turn the control back c'clockwise until the output is stable.

21) Open the "INTEGRATION INHIBIT" contact or remove the jumper between terminal numbers 9 and 10 on TS2.

22) Slowly, turn the "INTEGRATION RATE" (P5) control clockwise until the output just starts to oscillate. At this point, turn if back c'clockwise until stability is obtained, approximately 1.5 turns. The process output should be very close to or equal to the input command signal at this point.

    Note, in a flow or velocity application, the integral mode will be the primary control signal.

23) Slowly, adjust the "DERIVATIVE AMOUNT" (P3) control clockwise until the output just starts to oscillate. Turn the control back c'clockwise past the point where the process is stable until the process again just starts to oscillate. Count the turns between the two settings that cause instability. Finally turn the control back clockwise 1/2 the number of turns. The controller output should be stable.

24) Slowly, adjust the "PROPORTIONAL GAIN" (P14) control clockwise until the output just starts to oscillate, than turn the control back c'clockwise until the controller output is stable.

25) Quickly, increase the input command signal to 95% of it's maximum value. The process output should smoothly change to the new value and stabilize without excessive overshoot or ringing.

26) Quickly, decrease the input command signal to 5% of it's maximum value, again the process output should change to the new value and stabilize without excessive overshoot or ringing.

27) Vary the input command signal over it's range and observe the output of the process. *It must be stable at all points*.

    Once the process output stability, over the entire range of operation, is confirmed, you have a working PID control loop. If the process control element is subject to input variation (such as the secondary flow loop shown in the example) you should proceed with the feedforward compensation adjustment described below.

28) Set the input command voltage to approximately 75% of it's maximum value and allow the process output to stabilize.

29) Vary the flow to the secondary loop to introduce a series of rapid disturbances at the input to the process control element and observe the voltmeter response (a storage oscilloscope in place of the voltmeter will make life a lot easier). At each disturbance, adjust the "FEED FORWARD" (P4) control slightly clockwise. Repeat the process until the amount of output overshoot is equal to the amount of undershoot. This is the final setting. If the output starts to go unstable prior to obtaining the ideal response, reduce the "FEED FORWARD" control slightly c'clockwise and terminate the process.

    Note, in the example shown, the output from the input flow transducer must be a negative going signal as the flow in the secondary path increases. This will cause the output from the controller to increase, thus anticipating a need for a wider valve opening to maintain the setpoint flow value. If necessary the feedforward signal can be inverted by use of the difference amplifier or routed thru one of the scale sections.

30) This completes the PID loop tuning. Remove the input power from the controller and disconnect the voltmeter.

The PID loop tuning process described above will produce a working system in most applications. However, the loop is most likely not perfectly tuned in the classic sense. Experienced user's may wish to perform additional fine tuning in an attempt to further optimize the response of the system. Should you decide to attempt this, you should bear in mind the following PID loop relationships.

THE PID LOOP MUST BE STABLE UNDER ALL CONDITIONS!

Any process that oscillates or rings in an uncontrolled manner is not only not working, it may damage the equipment or cause injury to personnel.. If you are forced to choose between regulation and stability, always set the process for stable operation.

- Increasing the loops proportional gain setting will decrease the offset from the setpoint as well as the stability of the system while reducing it's response time. Proportional gain alone always causes the output signal to cycle around the setpoint.

STARTUP AND CALIBRATION INSTRUCTIONS, CON'T:

- Increasing the derivative amount will tend to reduce overshoot and ringing due to a step disturbance, however too much derivative action will lengthen the time required for the process to stabilize. Remember, that the only time the derivative action occurs is when the process variable signal is changing.
- Systems with large inertia's require more derivative action to prevent overshoots. However, too much derivative action may drive the controller output in the wrong direction and thus cause instability.
- Increasing the integration rate will decrease the offset from the setpoint as well as the system stability. Too fast a rate will cause the output to overshoot the correct steady state position. The correct amount of integration action will reduce the steady state error to zero.
- Systems that use the integral function must be adjusted so that the process variable signal will swing above and below the setpoint value. The integration drive signal is the process error. Unless the error signal changes polarity or reaches zero the integral output will continue to increase until it reaches the limit.
- Increasing the feed forward compensation will decrease the loop stability when subjected to rapid variations on the input. Properly adjusted, it will decrease the response time and minimize variations in the controlled variable. Remember, that the only time the feedforward action occurs is when the feedforward signal is changing. In most applications feedforward compensation is not required.
- Mechanical components that are too large or have slow response times will act is if the controller's overall gain has been increased. This is turn tends to reduce the stability of the loop.

CONTROLLER MODE SELECTION:

The primary control mode for a number of process applications is given in the table below. These suggestions are based upon experience and may differ for a specific application.

PRIMARY CONTROLLER MODE	CONTROLLED PROCESS
Proportional	Position, pressure, force, temperature and torque
Integral	Velocity, torque and tension.

Derivative and feedforward can be added to the primary control mode as required.

It is important that the controlled process be properly defined. Some processes at first glance can appear to be one thing, but in reality operate in a completely different mode. For example, a system that requires a constant pressure as the flow varies uses a pressure transducer as the feedback device. Variations from the system command pressure are compensated by adjusting the output from a flow control valve. This might a first glance appear to be a pressure control application, the table shows that proportional mode would be the primary control mode. A second look at the application indicates that this is really a velocity loop, thus the integral mode is the preferred mode for the controller. The point of this discussion is, take the time to analyze the loop before you try and tune it. This will make life a lot simpler, expedite the tuning process and produce better results.

SPECIFICATIONS:

DC INPUT POWER SUPPLY REQUIREMENTS:	+/- 10 VDC minimum with suffix AAA = 100
	+/- 15 VDC minimum with suffix AAA = 150
The maximum power supply voltage for all dc powered models is +/- 30 volts dc. The power supply must deliver a minimum of 40 ma., plus the transducer power supply current.	

SPECIFICATIONS, CON'T:

AC INPUT POWER SUPPLY REQUIREMENTS: 105 to 130 VAC with suffix AAA = 111

205 to 250 VAC with suffix AAA = 231

All ac line powered models will operate with line frequencies from 47 to 62 Hz.

AC INPUT POWER REQUIREMENT: 6 VA maximum with maximum transducer current.

TRANSDUCER POWER SUPPLY VOLTAGE +/- 5 volts dc with suffix AAA = 100

+/- 12 volts dc for all suffix AAA values, except 100.

TRANSDUCER POWER SUPPLY CURRENT: +/- 200 ma., maximum.

Refer to the transducer power supply connection section for thermal limit notes and calculation.

TRANSDUCER POWER SUPPLY REGULATION: Line regulation = .8% maximum.

Load regulation = .5% maximum.

Thermal regulation = .07% per watt, maximum.

Line regulation is with the input power supply varied over the limits specified in the power supply requirement section, above.

Load regulation is with the transducer power supply output currents from 15 to 200 ma.

RATED INPUT VOLTAGE SIGNALS FOR ALL FUNCTIONS EXCEPT THE AUXILIARY SECTIONS: +/- 3 volts dc with suffix BBB = 030

+/- 5 volts dc with suffix BBB = 050

+/- 10 volts dc with suffix BBB = 100

All voltage rated inputs with internal impedance will withstand up to 100 volts dc without damage.

RATED INPUT VOLTAGE SIGNAL TO THE AUXILIARY SECTIONS: +/- 100 volts dc, all models.

RATED INPUT CURRENT SIGNAL TO THE AUXILIARY SECTIONS: + 4 to + 20 ma. dc, all models.

INPUT SIGNAL IMPEDANCE: All voltage input terminals are 100K ohms, except terminal numbers 2, 5 and 7 on terminal block TS2. These input signal lines require the addition of external impedance in series with the applied input signals. The current signal line input on the auxiliary sections has as impedance of 250 ohms. The 250 ohm impedance will require a compliance voltage of 5 volts at 20 ma. input current.

RATED OUTPUT VOLTAGE SIGNAL, ALL SECTIONS: +/- 3 volts dc with suffix CCC = 030.

+/- 5 volts dc with suffix CCC = 050

+/- 10 volts dc with suffix CCC = 100

RATED OUTPUT CURRENT, ALL SECTIONS: +/- 5 ma. with all suffix CCC versions

The output currents are specified with the input power supply set to +/- 10 volts dc.

OUTPUT VOLTAGE STABILITY AND DRIFT: Better than 1% at unity gain.

PID SECTION, PROPORTIONAL GAIN RANGE: 0% to 20% per 1% of input volts.

SPECIFICATIONS, CON'T:

PID SECTION, INTEGRATION RATE RANGE: Less than 1 to a maximum of 100 repeats per minute.

PID SECTION, DERIVATIVE TIME CONSTANT RANGE: 0 to 150 msec., with 0 to 100% step change.

PID SECTION, FEED FORWARD TIME CONSTANT RANGE: 0 to 150 msec., with 0 to 100% step change.

PID SECTION, OUTPUT VOLTAGE LIMIT ADJUSTMENT RANGE: 0 to 100% of the rated output range.

PID SECTION, OUTPUT BIAS ADJUSTMENT RANGE: +/- 15% of rated output range.

AUXILIARY SECTION, VOLTAGE GAIN ADJUSTMENT RANGE: +/- .1 to +/- 10.1 volts per input volt.

AUXILIARY SECTION, CURRENT GAIN ADJUSTMENT RANGE: +/- .0075 to +/- .75 volts per input ma.

AUXILIARY SECTION, BIAS OR ZERO ADJUSTMENT RANGE: +/- 50% of the input range.

DIFFERENTIAL SECTION GAIN:
1, fixed with suffix D = 0
5, fixed with suffix D = 1
10, fixed with suffix D = 2

Fixed gain is applied to the differential input signal.

TRANSDUCER POWER SUPPLY ADJUSTMENT RANGE: +/- 10% of nominal, minimum.

ADJUSTMENT POTENTIOMETERS: All are twenty five (25) turns, nominal. Totally enclosed and sealed against dirt and other contaminates per MIL-STD-202. Method 103.

OPERATING TEMPERATURE: - 20 degrees to + 55 degrees C.

Extended temperature range operation is available, contact Datatran's Sales Department for availability and price.

PART NUMBER IDENTIFICATION:

All PID controller circuit board assemblies utilize the same basic model series identifier number. This number is modified with a suffix to indicate a particular combination of options. The format for the complete part number is illustrated in the example below:

Option identifier suffix groups

Model series identifier

C2844-AAA-BBB-CCC-DE

PART NUMBER SUFFIX GROUP EXPLANATION	
SUFFIX	**DESCRIPTION**
AAA	Minimum power supply voltage
BBB	Maximum input signal voltage
CCC	Maximum output signal voltage
D	Differential section fixed gain value.
E	Factory installed option identifier

Parts shipped from the factory will have the correct alphanumeric option identifier in place of the suffix letters indicated in the table above.

ORDERING INFORMATION:

Purchase orders must include a complete part number. Refer to the C2844 model series selection sheet for a complete listing of all available models.

A number of modifications are available for this unit. Some of the most common options include special input and output signal ranges, operation at temperatures between -55 and +100 degrees C, gain and stability adjustment changes as well as special OEM versions. Most of these modifications can be accomplished at little or no additional cost. Interested user's are invited to contact Datatran Labs, Inc. for a quotation pertaining to any special options that they may require.

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