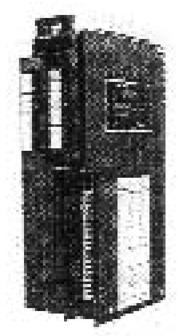
Allen-Bradley Proportional/Integral/Derivative Control (2-Loop) Module

(Cat. No. 1771-PD)

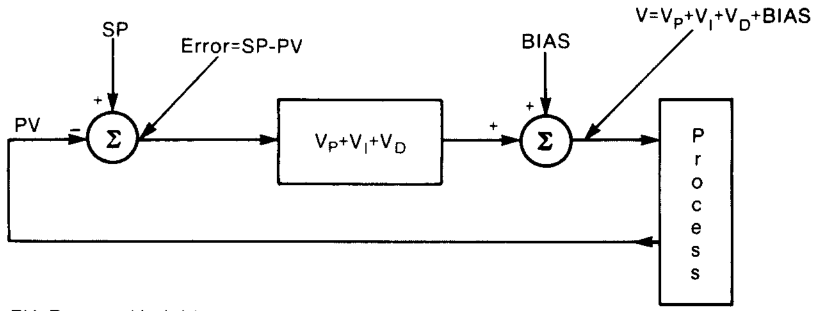
Product Data



General Description

The Proportional/Integral/Derivative Control (2-Loop) Module Assembly (cat. no. 1771-PD) is an intelligent I/O Module that performs closed loop PID control. The PID module is a process controller. It monitors the input process variable, compares the input to the desired set point, and calculates the analog output based on the control algorithm programmed in the module (figure 1). It can be used with a variety of I/O devices that operate in the +4 to +20mA or +1 to +5V DC range.

Figure 1
PID Closed Loop Control



PV=Process Variable

SP=Set Point

A-B	ISA
V = Controller Output	Controller Output
V_P = Proportional Term K_P	Controller Gain K_c
V_I = Integral Term K_I	Reset Term $1/T_i$
V_D = Derivative Term K_D	Rate Term T_d

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You have a choice of control algorithm:

- A-B
- ISA

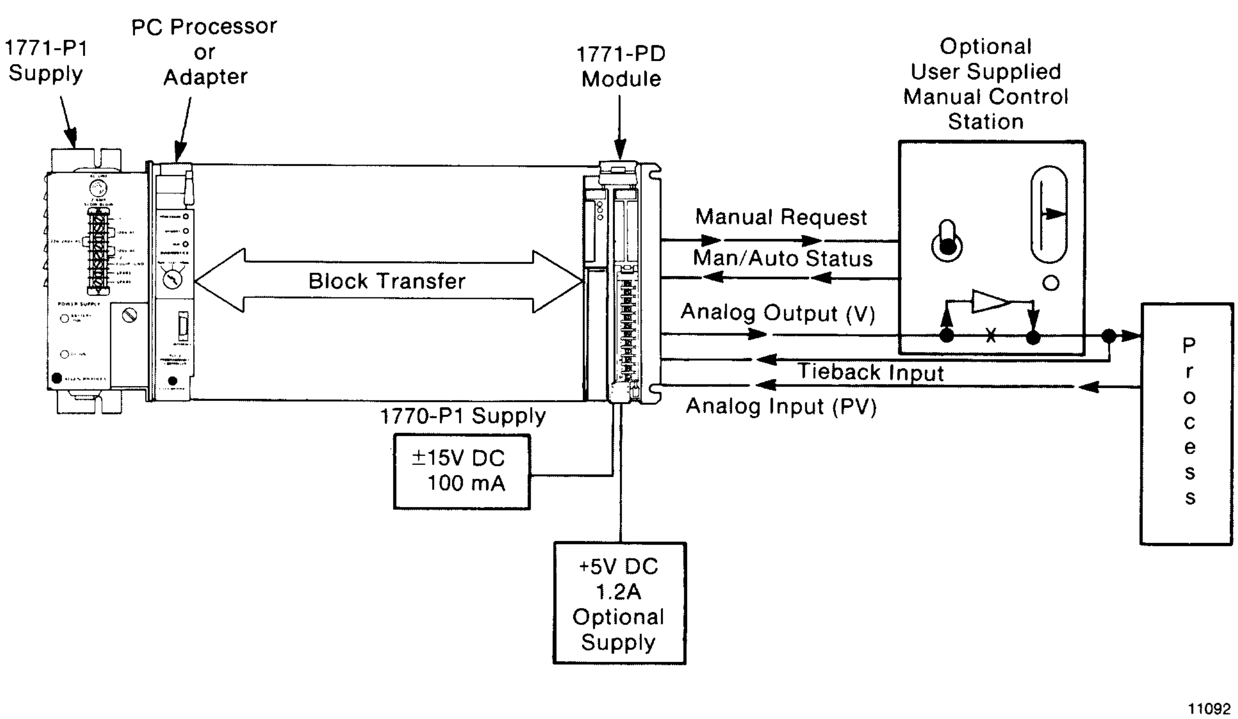
Refer to Comparing ISA and A-B Algorithms and the end of this data sheet.

Block transfer programming is used to communicate between the PID module and the PC processor. The PC processor writes loop configuration data such as gain constants, set points, filter values, limit and alarm values to the PID module and reads status data such as analog input values, analog output values, alarm limits and diagnostics from the PID module. The PID module can be used with any Allen-Bradley PC processor that has block transfer capability, and uses 1771-I/O.

The PID module has five levels of fault tolerance. If communication with the PC processor is lost or withheld, the module can operate alone in soft fault mode using the last values transferred from the PC processor. If a fault in module hardware is detected, the module automatically sets the output to a predetermined value and generates a signal to transfer control to an optional user-supplied manual control station. When a manual control station is used, the manually controlled output overrides the output set by the module. Control can be returned to the PID module by a "bumpless" transfer that prevents an undesirable output surge. Another level of fault tolerance is the module's response to loss of voltage. If +5V DC is lost, outputs go to a predetermined maximum of minimum value. If ±15V DC is lost, outputs go to minimum value. Lastly, the PID module can operate from a power supply that is independent of the I/O chassis power supply.

An overview of a PID module control system is shown in figure 2. Once properly configured, the PID module can operate independently of the PC processor. Or, the PID module/PC processor combination can perform adaptive control where the PC processor can continually adjust the PID module's control algorithm based on process changes monitored by the PC processor. In addition, PID modules can be used with PC processors in distributed control systems using the data highway.

Figure 2
System Overview



Loop Features

The PID module can control one or two PID closed loops. The two loops can be independent or linked together by an advanced control function such as cascade or decoupling. Expanded loop features can be chosen in addition to standard features to suit the application. All features are selectable by settings bits in the data table with the exception of the I/O range, the source of +5V DC, and the fault response to a hardware failure, or loss of +5V DC (which are selected using internal configuration plugs). Write block transfers to the module allow program logic to enable the following features:

Standard Features for Input Conditioning

- detect the loss of process variable input
- read the process variable at the PC processor
- substitute a value calculated by the PC processor for use as the process variable
- take the normalized square root of the process variable
- digitally filter the process variable

Standard Control Features

- select direct or reverse acting control
- download a set point from the PC processor
- limit and/or set an alarm on the error signal
- perform error dead band (zero crossing)
- set an alarm when the error exceeds the dead band
- select the A-B or ISA PID algorithm
- select error or error squared conditioning of the proportional and/or integral error
- select whether the derivative function operates on the error or the process variable
- set an alarm on the proportional term
- limit and/or set an alarm on the integral term
- limit and/or set an alarm on the derivative term

Standard Features for Output Conditioning

- limit and/or set an alarm on the PID algorithm output
- read the PID algorithm output at the PC processor

- override the PID algorithm output from the PC processor
- interface directly with a manual control station (bumpless transfer)
- hold the PID algorithm output for independent loop tuning
- hold the bias/feedforward term for independent loop tuning
- download an output bias from the PC processor

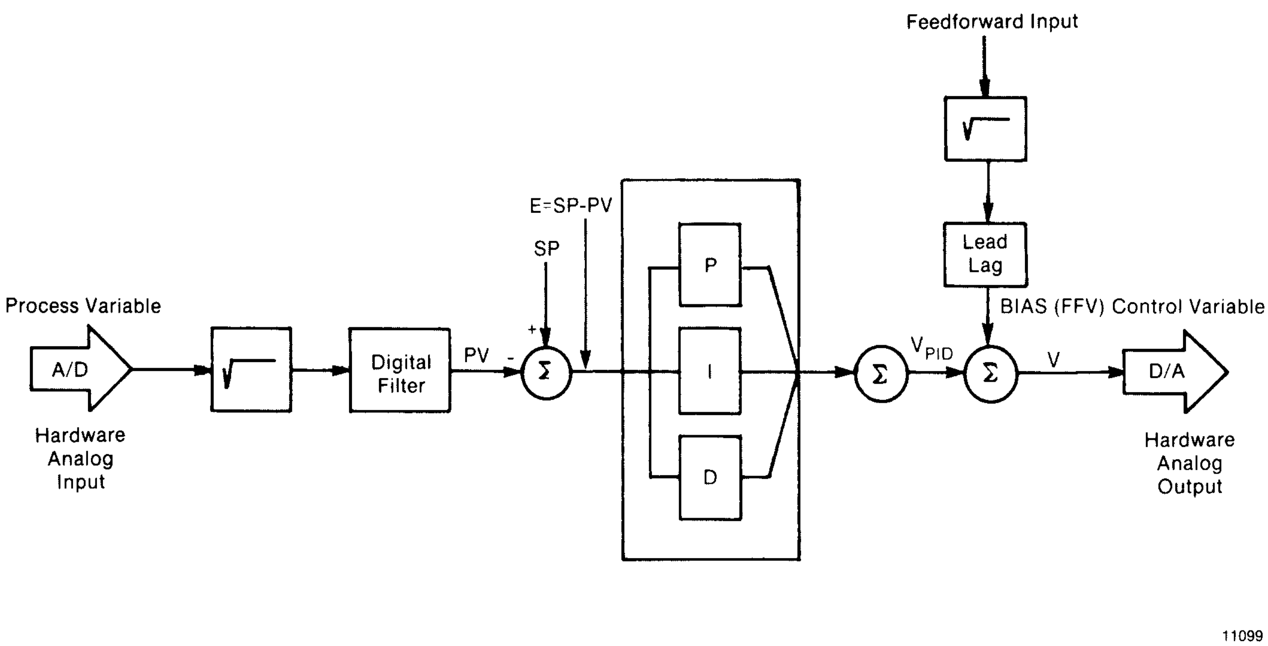
Expanded Features

- perform scaling on the process variable, set point and/or error
- use the tieback as the feedforward input
- take the normalized square root of the feedforward input
- add a feedforward offset
- multiply the feedforward term by a constant
- perform lead/lag filtering on the feedforward term
- download a feedforward value from the PC processor
- cascade the output of loop 1 into the set point of loop 2
- decouple the VPID output of loop 1 into the feedforward input of loop 2

The module performs anti-reset wind-up on the integral output term. When a limit is set on the PID algorithm output, the integral output term is adjusted to compensate for changes in other algorithm output terms.

A simplified flow chart of the PID loop algorithm (figure 3) shows selected standard and expanded loop features.

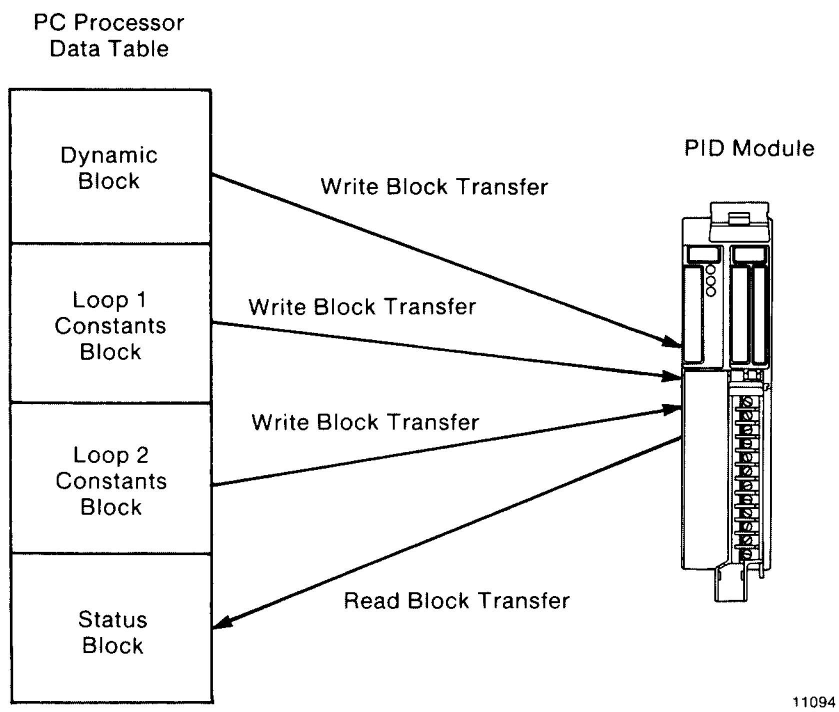
Figure 3
Simplified PID Algorithm



Block Transfer Programming

PID module features are selected by setting word values and control bits in data table block files. Block files are transferred between the PC processor and the PID module by bidirectional block transfers (figure 4).

Figure 4
Multiple Block Concept



Loop data must be loaded initially from the PC processor to the PID module by a power-up load/enter sequence. Thereafter, program logic can enable continuous bidirectional communication (dynamic/status toggle sequence), or periodic bidirectional block transfers when the module operates independently of the PC processor. Either way, the PC processor can continuously monitor the status of the PID module: by continuously reading the status block by read block transfers, or by examining the module's status monitor byte which does not require block transfers.

Multiple Block Concept

Data block files are areas of the PC processor data table used to store loop control words and loop values. The blocks have corresponding storage areas in the PID module. Block files required by the PID module are:

Dynamic block — contains values for both loops which may change frequently. Once data has been initially loaded into the PID module, the dynamic block values can be changed at any time with a single write block transfer. The dynamic block contains 10 words for 1-loop operation or 17 words for 2-loop operation.

Loop 1 Constants Block — contains values which seldom change. Once data has been initially loaded into the PID module, the loop constants can be changed only by initiating a load/enter sequence of multiple block transfers. The loop constants block contains 12 words for standard features or 19 words for standard and expanded features.

Loop 2 Constants Block — (similar to Loop 1 Constants Block)

Status Block — is used to report the current status of the PID module and any alarm condition detected by the module. The status block also prompts the next write block transfer of a dynamic block or loop constants block. The status block contains 11 words for 1-loop operation or 18 words for 2-loop operation.

A summary of the words used to store feature values and associated control bits is listed in table A.

Table A
Control and Value Words

Dynamic Block		
Word	**Title**	**Range**
W01	Master Control Word	—
W02	Control Word	—
W03	Dynamic Block Start Address	—
W04	Loop 1 Block Start Address	—
W05	Set Analog Output 1	0-4095
W06	Set Point 1	0-4095
	Scaled	±99990
W07	Proportional Gain 1	0-9999
W08	Bias 1	±9999
W09	Process Variable 1	0-4095
W10	Feedforward Input 1	±4095
W11	Loop 2 Block Start Address	—
W12	Set Analog Output 2	0-4095
W13	Set Point 2	0-4095
	Scaled	±99990
W14	Proportional Gain 2	0-9999
W15	Bias 2	±9999
W16	Process Variable 2	0-4095
W17	Feedforward Input 2	±4095

Table A
Control and Value Words (continued)

Loop 1 Constant Block

Word	Title	Title Range
W18	Loop Control Word A	—
W19	Loop Control Word B	—
W20	Input Filter Time Constant 1	0-999.9
W21	Maximum Negative Error 1	0-4095
W22	Maximum Positive Error 1	0-4095
W23	Dead Band 1	0-4095
W24	Integral Gain 1	0-999.9
W25	Derivative Gain 1	0-9999
W26	Integral Term Limit 1	0-9999
W27	Derivative Term Limit 1	0-9999
W28	Minimum Output Limit 1	0-4095
W29	Maximum Output Limit 1	0-4095
W30	Loop 1 Expanded Control Word	—
W31	Minimum Scaling Value 1	±99990
W32	Maximum Scaling Value 1	±99990
W33	Feedforward Offset 1	0-9999
W34	Feedforward Gain 1	0-9999
W35	Lead Time Constant 1	0-999.9
W36	Lag Time Constant 1	0-999.9

Loop 2 Constants Block

Word	Title	Range
W38	Loop 2 Control Word A	—
W39	Loop 2 Control Word B	—
W40	Input Filter Time Constant 2	0.999.9
W42	Maximum Negative Error 2	0-4095
W42	Maximum Positive Error 2	0-4095
W43	Dead Band 2	0-4095
W44	Integral Gain 2	0-999.9
W45	Derivative Gain 2	0-9999
W46	Integral Term Limit 2	0-9999
W47	Derivative Term Limit 2	0-9999
W48	Minimum Output Limit 2	0-4095
W49	Maximum Output Limit 2	0-4095
W50	Loop 2 Expanded Control Word	—
W52	Minimum Scaling Value 2	±99990
W52	Maximum Scaling Value 2	±99990
W53	Feedforward Offset 2	0-9999
W54	Feedforward Gain 2	0-9999
W55	Lead Time Constant 2	0-999.9
W56	Lag Time Constant 2	0-999.9

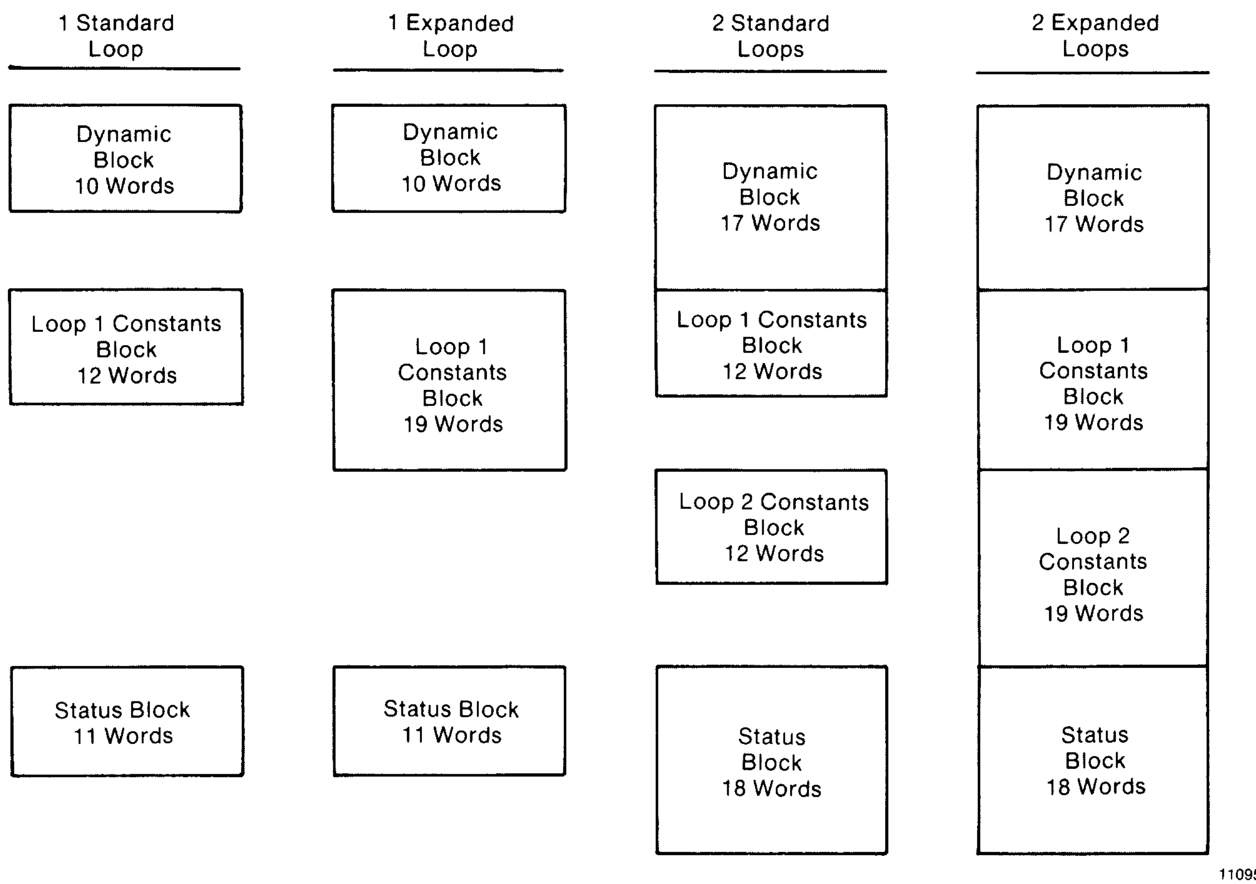
Table A
Control and Value Words (continued)

Status Block		
Word	**Title**	**Range**
W57	For Future Use	—
W58	Alarm (both loops)	—
W59	Next Block Start Address	—
W60	Loop Time/Diagnostic	—
W61	Loop Status 1	—
W62	Loop Error 1	± 4095
	Scaled	± 99990
W63	Read Loop 1 Output	0-4095
W64	Read Analog Input 1	0-4095
W65	Read Process Variable 1	0-4095
	Scaled	± 99990
W66	Read Tieback Input 1	0-4095
W67	Read Feedforward Value 1	± 9999
W68	Loop Status 2	—
W69	Loop Error 2	± 4095
	Scaled	± 99990
W70	Read Loop 2 Output	0-4095
W71	Read Analog Input 2	0-4095
W72	Read Process Variable 2	0-4095
	Scaled	± 99990
W73	Read Tieback Input 2	0-4095
W74	Feedforward Value 2	± 9999

Storage Requirements

Data table storage requirements depend on the number of control loops and on whether expanded features have been selected. Data blocks for storing the values of standard and expanded features can be arranged consecutively in the data table. A minimum of 33 words is required for one standard loop. A maximum of 74 words is required for two expanded loops (figure 5).

Figure 5
Block File Memory Requirements



Display of Data Blocks

By placing the data blocks consecutively in the data table, they can be displayed conveniently in a single data monitor display where the word numbers and position numbers of the display correspond.

Programming Considerations

The PID module has considerable programming versatility. A load/enter sequence is used to configure the module with selected features, start PID control, or to change loop constants. Data can be transferred to the module and stored indefinitely in buffer memory until activated by a program logic command.

Bidirectional block transfers can be used for continuous communication between PID module and PC processor. The PC processor reads the status block, then writes the dynamic block to the module in the next I/O scan. Continuous bidirectional block transfer is useful for adaptive control where the PC processor adjusts loop values based on data received by monitoring the process.

The PID module is capable of operating independently without continuous block transfer communication with the PC processor. Once the module has been initialized, the module's general status can be monitored continuously through the status monitor byte without block transfers. The status monitor byte reports the module's detection of a module hardware fault, loss of input, or loss of analog power.

Fault Response

The module detects internal hardware failures and loss of communication with the PC processor. The manner in which the module responds to a detected fault is user selectable.

Hardware Fault

Module response to a detected hardware fault can be selected with internal programming (jumper) plugs prior to installation (table B). In the event of a hardware fault, programming plug selection causes the module to respond in one of the following ways:

- sets the analog output to the minimum value (+4mA or +1V DC)
- holds the analog output to the last value before the fault occurred
- sets the analog output to the maximum value (+20mA or +5V DC)

Also, when the module detects a hardware fault it automatically transfers control of the loop(s) to an manual control station (if used). The output of the manual control station can be controlled manually and overrides the module's output.

Loss of Voltage

Module response to a detected loss of +5V DC can be selected, as well.

- sets analog output to minimum value (+4mA or +1V DC)
- sets analog output to maximum value (+20mA or +5V DC)

Outputs go to minimum value if ±15V DC is lost.

Table B
Programming Plug Positions

Function		Choice	Plug Position
Digital Board hard fault output		hold max/min, hold last state	E2 LEFT for max/min, E2 RIGHT for last state
source of +5V DC		backplane external	E10 IN for backplane E10 OUT for external
Analog Board hard fault output	1 2	maximum, minimum maximum, minimum	E5 OUT for max, IN for min. E4 OUT for max, IN for min.
output range	1 2	I, V I, V	E3, E6, E8 as shown in figure 6 E1, E2, E7 as shown in figure 6
input range	1 2	I, V I, V	E15 IN for I, OUT for V E14 IN for I, OUT for V
tieback input	1 2	I, V I, V	E11 IN for I, OUT for V E12 IN for I, OUT for V
compliance		standard, additional	E18 as shown in figure 6 E21, E22 IN for standard, OUT for additional.
source of +5V DC		back plane, external	E23, E24 as shown in figure 6

Note: The current range I is +4 to +20mA, the voltage range is +1 to +5V DC.

Communications Fault

The PID module detects the loss of communication with the PC processor (soft fault). Program logic enables the module to respond in one of the following ways in response to a soft fault:

- sets the analog output to the minimum value (+4mA or +1V DC)
- holds the analog output to the last PID algorithm value before the soft fault occurred
- performs PID control based on the last values transferred to the PID module before the soft fault occurred
- sets the analog output to the maximum value (+20mA or +5V DC)

Switch position 1 on the last state switch assembly (I/O chassis backplane) must be set to the position for the soft fault response to operate. Note that this will cause the outputs of other modules in the same chassis to be de-energized when they detect a fault.

The response for each loop can be selected independently for a hardware or communications fault.

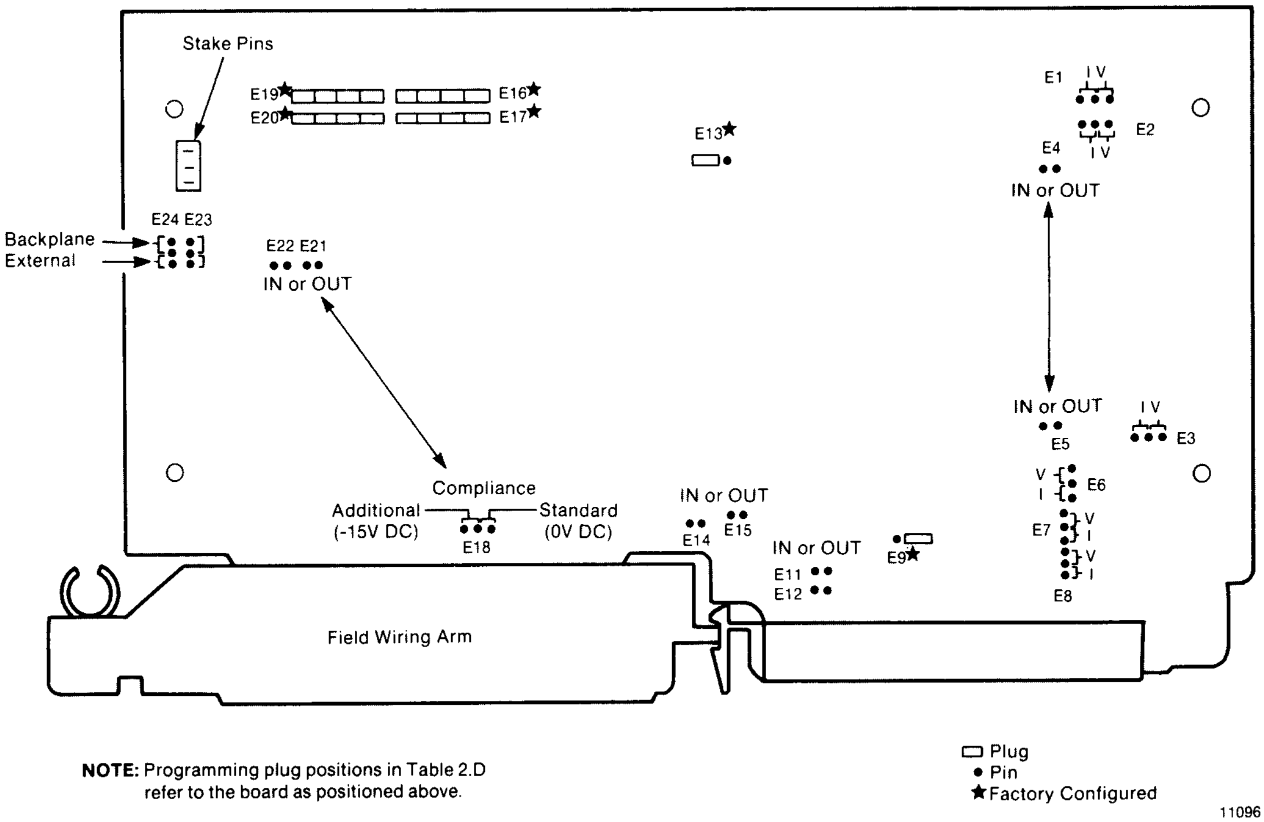
Hardware

The PID module is a dual-slot module that occupies both slots of a module group. The front panel contains three LED indicators and a write-on label to record I/O ranges and the last date of calibration. Internally, the module contains a digital and an analog printed circuit board. The analog board is located beneath the module cover containing the label that identifies the connections to the field wiring arm.

Internal Selections

The PID module can accommodate a wide variety of applications. This is made possible by positioning a number of programming plugs inside the module. Selectable functions and corresponding programming plugs on both circuit boards are listed in table B. Programming plug locations on the analog circuit board are shown in figure 6.

Figure 6
Programming Plug Locations (Analog Board)



NOTE: Programming plug positions in Table 2.D refer to the board as positioned above.

Indicators

The front panel LED indicators allow an operator to observe the operating condition of the module. The indicators will be on, off or flashing (table C).

Table C
LED Indicators

Indicator	State	Condition
FAULT (red)	off on	normal operation hardware fault
RUN (green)	on flashing off toggle	normal operation power-up (un-programmed) not running loss of ± 15V DC
STAND ALONE (yellow)	off flashing toggle on	normal operation soft fault loss of ± 15V DC block transfer program error
all three	off	calibration mode

Power Requirements

The PID module requires 1.2A at +5V DC from the I/O chassis backplane. The module also requires 100mA at +15V DC and 100mA at -15V DC from an external supply through the field wiring arm (table D).

Table D
+15V DC Power Supply

Specifications	+15Volts	-15Volts
Current	100mA	100mA
Voltage Tolerance	1%	1%
Regulation (type)	Series	Series
Line Regulation (for 10V AC input change)	± 0.2%	± 0.2%
Load Regulation (no load to full load)	± 1.0%	± 1.0%
Ripple	1mVpp	1mVpp
Overvoltage Protection	+18 volts	-18 volts
Current Limit (percent of full load)	125%	125%

The source of +5V DC can be an optional external power supply wired to the field wiring arm (table E). This allows the module to be powered entirely from power supplies independent of the backplane.

Table E
+5V DC (Optional) Power Supply

Specifications	+5V DC
Voltage (at field wiring arm)	5.05V DC
Current	1.2A
Voltage regulation (sum of all deviations due to line, load and ripple)	± 0.15V DC
Rise time (to 4.75V DC)	10ms

Wiring

Terminal identification and connections to the module are summarized in figure 7. Typical wiring (less shielding) for I-loop control with a manual control station is shown in figure 8. Proper shielding is essential to minimize coupling of electrical noise to the PID module. The optimum grounding point(s) will vary between inputs and outputs, and voltage or current devices. Refer to the PID Module User's Manual publication no. 1771-6.5.9) for proper shielding of input and output devices.

Figure 7
Terminal Identification and Connections

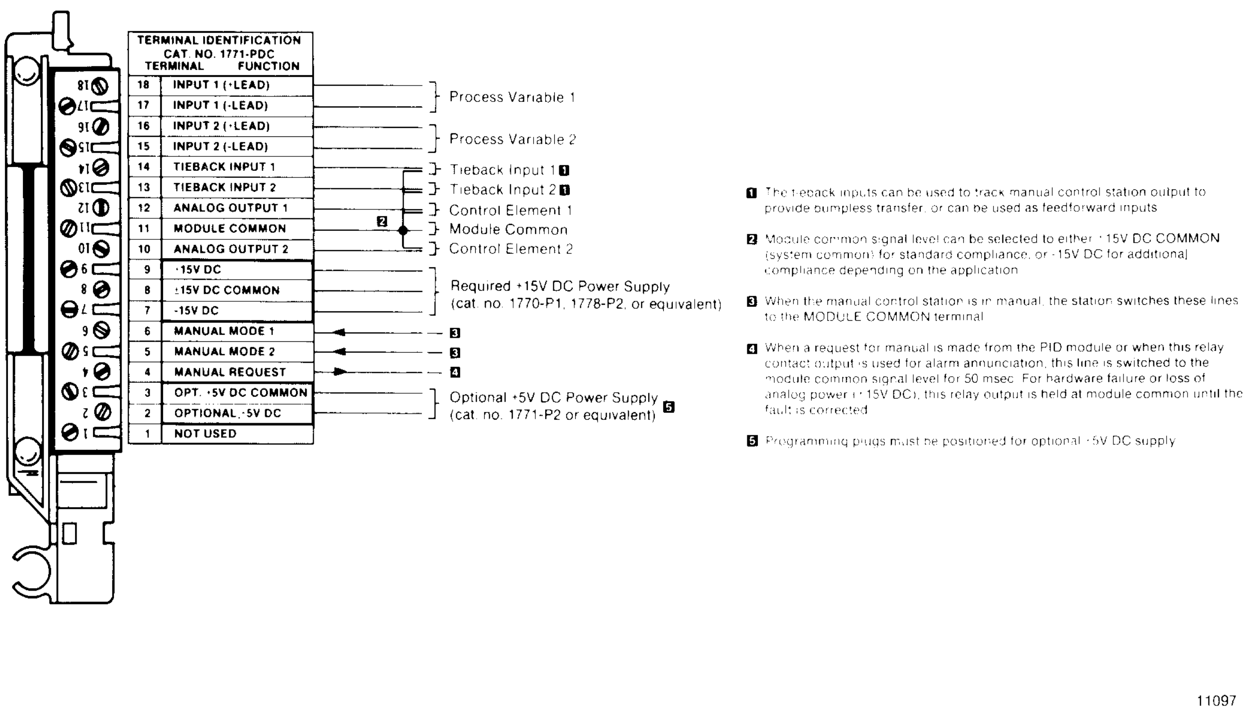
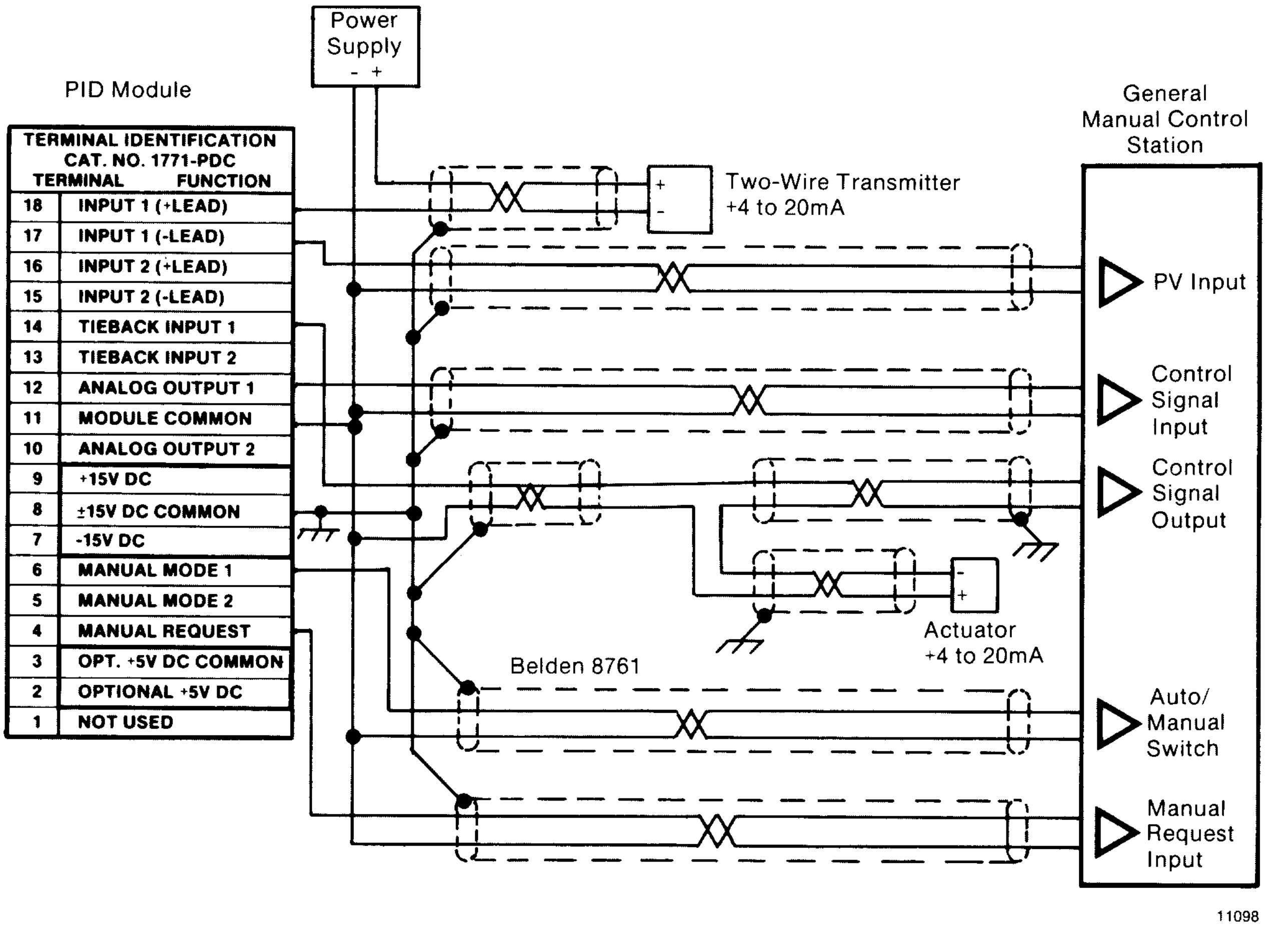


Figure 8
Typical Connections for 1-Loop Control



Additional Compliance

The maximum allowable load impedance in current mode using standard compliance is 500 ohms. Additional compliance can be established for one or two loops, if analog outputs 1 and 2 and tieback inputs 1 and 2 are selected for current mode. Additional compliance allows a maximum load impedance of 1250 ohms and is obtained by internally referencing module common to -15V DC.

Keying

Keying bands should be used to guard against placing another type of module in a module group reserved for the PID module. Keying band positions are as follows:

slot 0 (left)	slot 1 (right)
between 8 and 10	between 2 and 4
between 18 and 20	between 28 and 30

Comparing ISA and A-B Algorithms

The ISA algorithm and the Allen-Bradley algorithm are different although they achieve the same closed loop control. By understanding the differences, you can convert proportional gain, reset and rate values from ISA to equivalent A-B gain values.

ISA Algorithm

The equation for PID closed loop control is:

$$V_O = K_C\,(E) + K_C/T_I \int (E)\,dt + K_C\,(T_D) d(E)/dt$$

Where
- K_C = controller gain 1/T
- $1/T_I$ = reset term in repeats per minute
- T_D = rate term in minutes

A-B Algorithm

The equation for PID closed loop control is:

$$V_O = K_P(E) + K_I \int (E)dt + (K_D) d(E)/dt + \text{Bias}$$

Where
- Kp = proportional gain
- K_I = integral gain in inverse seconds
- K_D = derivative gain in seconds

Comparison

The ISA algorithm contains dependent variables. When you change your controller gain (K_C), you also change your integral and derivative values.

The A-B algorithm contains independent variables. You adjust the proportional, integral, and derivative terms independently.

ISA Algorithm	A-B Algorithm
Controller Gain K_C (dimensionless)	Proportional Gain K_P (dimensionless)
Reset Term $1/T_I$ (repeats per minute)	Integral Gain K_I (inverse seconds)
Rate Term T_D (minutes)	Derivative Gain K_D (seconds)

When using the A-B algorithm, you must convert the ISA controller gain, reset, and rate terms to gain values of the A-B algorithm.

Conversion

Convert ISA values to A-B values as follows:

$$K_P = K_C$$

$$K_I = \frac{K_P(I/T_I)}{60}$$

$$K_D = K_P(T_D)(60)$$

Example

If your desired ISA values are:

controller gain = K_C = 1
reset value = $1/T_I$ = 5 repeats per minute
rate term = T_D = 3 minutes

convert them to A-B gain values as follows:

proportional gain = $K_P = K_C = 1$

integral gain = $K_1 = \frac{(1)(5)}{60} = 0.083$

derivative gain = $K_D = (1)(3)(60) = 180$

Selecting the Algorithm

You select the ISA or A-B algorithm by setting a bit in the control word.

Specifications

Process Variable Inputs

Number

- process variable input 1
- process variable input 2

Configuration

- Differential

Range (user-selectable)

- +4 to +20mA
- +1 to +5V DC

Digital Resolution

- 12-bit binary, 1 part in 4095

Accuracy

- ± 0.1% of range at 25°C

Input Impedance

- 250 ohms (current)
- 10 megohms (voltage)

Common Mode Rejection Ratio

- 70dB DC

Common Mode Voltage Range

- ± 200V with respect to module common

Common Mode Input Resistance

- 2.5 megohms

Input Frequency Response

- -3dB at 1kHz

Maximum Allowable Input

- ± 30mA (current)
- 125V DC (voltage)

Temperature Coefficient

- ± 50 ppm/°C

Tieback Inputs

Number

- Tieback input 1
- tieback input 2

Configuration

- Single ended

Range (user-selectable)

- +4 to +20mA
- +1 to +5V DC

Digital Resolution

- 12-bit binary, 1 part in 4095

Accuracy

- ± 0.1% of range at 25°C

Input Impedance

- 250 ohms (current)
- 4.7 megohms (voltage)

Maximum Allowable Input

- ± 30mA (current)
- 25V rms (voltage)

Temperature Coefficient

- ± 50 ppm/°C

Analog Outputs

Number

- analog output 1
- analog output 2

Configuration

- Single ended

Range (user-selectable)

- +4 to +20mA
  (With output common internally referenced to power supply common, the output will drive up to a 500 ohm load over the full current range.)[1]
- +1 to +5V DC
  (500 ohms minimum load resistance, 10mA maximum load current)

Digital Resolution

- 12-bit binary, 1 part in 4095

Accuracy

- ± 0.1% of range at 25°C

Temperature Coefficient

- ± 50 ppm/°C

Contact Output

- Number
- one normally closed contact, held open

Peak Voltage

- 30V

Maximum Current

- 250mA

Maximum Power

- 3VA

Digital Inputs from Manual Control Station

- Two independent inputs for monitoring.

Power Requirements

Backplane or External (Digital Circuits)

- 1.2A at +5V DC

External (Analog Circuits)

- 100mA at +15V DC
- 100mA at -15V DC

Other

Loop Update Time

- 100msec, typical

Ambient Temperature Ratings

- Operational 0°C to 60°C (32°F to 140°F)
- Storage -40°C to 85°C (-40°F to 185°F)

Relative Humidity Rating

- 5% to 95% (without condensation)

Electrical Isolation

- 1500V rms (transient)
  (Isolation is achieved by optoelectronic coupling between I/O analog circuits and control logic)

Field Wiring Arm

- 1771-WF

Keying

- Left connector (slot 0)
  between 8 and 10,18 and 20
- Right connector (slot 1)
  between 2 and 4, 28 and 30

[1] If all analog outputs and tieback inputs used are selected to current mode, the compliance of the analog outputs can be extended from 500 ohms (standard compliance) to 1250 ohms (additional compliance). This is achieved by internally referencing the outputs to -15V DC.

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