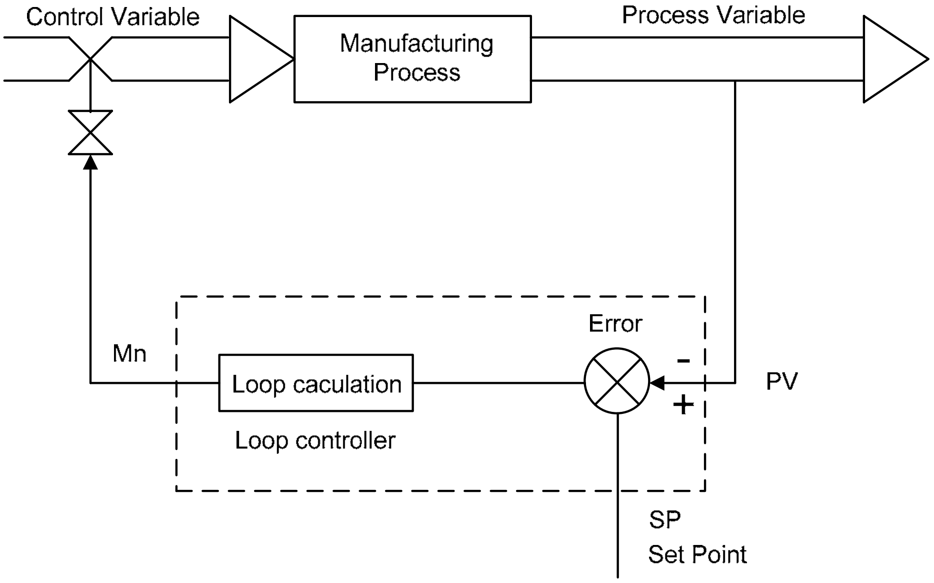
Chapter 22 General Purpose PID Control

22.1 Introduction of PID Control

As the general application of process control, the open loop methodology may be good enough for most situations, because the key control elements or components are more sophisticated, and the performances of which are getting better, there is no doubt, the stability and reliability may meet the desired requirement. It is the way to get not bad C/P value with great economic consideration. But the characteristics of the elements or components may change following the time eclipse and the controlling process may be affected by the change of loading or external disturbances, the performance of open loop becomes looser; it is the weakness of such solution. Thus, closed loop (with the sensors to feedback the real conditions of controlling process for loop calculation) PID control is one of the best choices for manufacturing process to make perfect quantity and best products.

FBs-PLC provides digitized PID mathematical algorithm for general purpose application, it is enough for most of applications, but the response time of loop calculation will have the limitation by the scan time of PLC, thus it must be taken into consideration while in very fast closed loop control.

For an introduction to key parts of a control loop, refer to the block diagram shown below. The closed path around the diagram is the "loop" referred to in "closed loop control".



Typical Analog Loop Control System

22.2 How to Select the Controller

Depends on the requirement, the users may apply the suitable controller for different applications; it is much better of the thinking that the control algorithm is so simple and easy to operate and the final result will be good enough, that's all. Therefore comes the answers, there are three types of controller could be activated from the PID mathematical expression, these are so called "Proportional Controller”, "Proportional + Integral Controller" and "Proportional + Integral + Derivative Controller". The digitized mathematical expression of each controller shown bellows.

22.2.1 Proportional Controller

The digitized mathematical expression as follows:

$$Mn = (D4005/Pb) \times (En) + Bias$$

Where,

Mn ：Output at time “n”.

D4005：The gain constant, the default is 1000, it's range is 1～5000.

Pb ：Proportional band

- the expression stating the percent change in error required to change the output full scale.

〔Range：1～5000, unit in 0.1%；Kc(gain)=D4005/Pb〕

En ：The difference between the set point (SP) and the process variable (PV) at time "n";

En = SP - PVn

Ts ：Solution interval between calculations（Range：1～3000, unit in 0.01S）

Bias ：Offset to the output（Range：0～16383）

The algorithm of "Proportional Controller" is very simple and easy to implement, and it takes less time for loop calculation. Most of the general applications, this kind of controller is good enough, but it needs to adjust the offset（Bias）to the output to eliminate the steady state error due to the change of set point.

22.2.2 Proportional + Integral Controller

The digitized mathematical expression as follows:

$$Mn = (D4005/Pb) \times (En) + \sum_{0}^{n} [(D4005/Pb) \times Ki \times Ts \times En] + Bias$$

Where,

Mn ： Output at time “n”.

D4005：The gain constant, the default is 1000, it's range is 1～5000.

Pb ： Proportional band 〔Range：1～5000，unit in 0.1%；Kc(gain)=D4005/Pb〕

En ： The difference between the set point (SP) and the process variable (PV) at time "n";

En = SP - PVn

Ki ： Integral tuning constant（Range：0～9999，it means 0.00～99.99 Repeats/Minute）

Ts ： Solution interval between calculations（Range：1～3000, unit in 0.01S）

Bias ： Offset to the output（Range：0～16383）

The most benefit of the controller with integral item is to overcome the shortage of the "Proportional Controller" mentioned above; via the integral contribution, the steady state error may disappear, thus it is not necessary to adjust the offset manually while changing the set point. Almost, the offset（Bias）to the output will be 0.

22.2.3 Proportional + Integral + Derivative Controller

The digitized mathematical expression as follows:

$$Mn = (D4005/Pb) \times (En) + \sum_{0}^{n} [(D4005/Pb)\times Ki\times Ts\times En] \quad - [(D4005/Pb)\times Td\times(PVn - PV_{n-1})/Ts] + Bias$$

Where,

Mn ：Output at time “n”.

D4005：The gain constant, the default is 1000, it's range is 1～5000.

Pb ：Proportional band 〔Range：1～5000，unit in 0.1%；Kc(gain)=D4005/Pb〕

En ： The difference between the set point (SP) and the process variable (PV) at time "n";
En = SP - PVn

Ki ： Integral tuning constant（Range：0～9999，it means 0.00～99.99 Repeats/Minute）

Td ：Derivative tuning constant （Range：0～9999，it means 0.00～99.99 Minute）

PVn ： Process variable at time “n”

PV_{n-1} ： Process variable when loop was last solved

Ts ：Solution interval between calculations（Range：1～3000, unit in 0.01S）

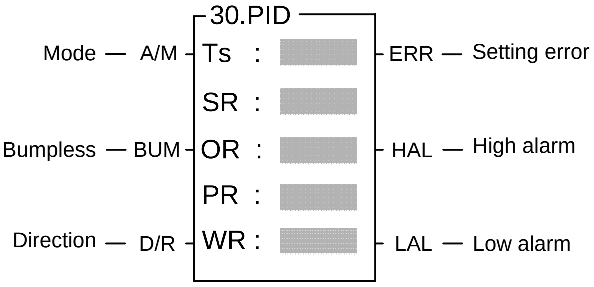
Bias ：Offset to the output（Range：0～16383）

Derivative item of the controller may have the contribution to make the response of controlling process smoother and not too over shoot. But because it is very sensitive of the derivative contribution to the process reaction, most of applications, it is not necessary of this item and let the tuning constant (Td) be equal to 0.

22.3 Explanation of the PID Instruction and Example Program Follows

The followings are the instruction explanation and program example for PID (FUN30) loop control of FBs-PLC.

Ladder symbol



Range / Operand	HR	ROR	DR	K
	R0 ｜ R3839	R5000 ｜ R8071	D0 ｜ D3999	
Ts	○	○	○	1～3000
SR	○	○*	○	
OR	○	○*	○	
PR	○	○*	○	
WR	○	○*	○	

Ts ：Solution interval between calculations
（1～3000 ; unit in 0.01S）

SR ：Starting register of loop settings ;
it takes 8 registers in total.

OR ：Output register of PID loop operation.

PR ：Starting register of loop parameters;
it takes 7registers.

WR ：Staring register of working registers
for this instruction ;
it takes 5 registers and can't be
repeated in using.

- The FBs-PLC software algorithm uses mathematical functions to simulate a three-mode (PID) analog controlling technique to provide direct digital control. The control technique responds to an error with an output signal. The output is proportional to the error, the error's integral and the rate of change of the process variable. Control algorithms include, P, PI, PD and PID which all include the features of auto/manual operation, bumpless/balanceless transfers, reset wind-up protection, and adaptive tuning of gain, integral, and derivative terms.
- The digitized mathematical expression of FBs-PLC PID instruction as bellows:

$$\mathrm{Mn} = (\mathrm{D4005}/\mathrm{Pb}) \times (\mathrm{En}) + \sum_{0}^{n} [(\mathrm{D4005}/\mathrm{Pb})\times \mathrm{Ki}\times \mathrm{Ts}\times \mathrm{En}] - [(\mathrm{D4005}/\mathrm{Pb})\times \mathrm{Td}\times(\mathrm{PVn}-\mathrm{PVn\text{-}1})/\mathrm{Ts}] + \mathrm{Bias}$$

Where,

Mn ： Output at time “n”

D4005 ： The gain constant, the default is 1000, which can be set between 1～5000.

Pb ： Proportional band
- the expression stating the percent change in error required to change the output full scale.
〔Range：1～5000，unit in 0.1%；Kc(gain)=D4005/Pb〕

Ki ： Integral tuning constant （Range：0～9999，it means 0.00～99.99 Repeats/Minute）

Td ： Derivative tuning constant （Range：0～9999，it means 0.00～99.99 Minute）

PVn ： Process variable at time “n”

PV_{n-1} ： Process variable when loop was last solved

En ： The difference between the set point (SP) and the process variable (PV) at time "n";
En = SP - PVn

Ts ： Solution interval between calculations（Range：1～3000, unit in 0.01S）

Bias ： Offset to the output（Range：0～16383）

Principle of PID parameter adjustment

- As the proportional band (Pb) adjustment getting smaller, the larger the proportional contribution to the output. This can obtain a sensitive and rapid control reaction. However, when the proportional band is too small, it may cause oscillation. Do the best to adjust “Pb” smaller (but not to the extent of making oscillation), which could increase the process reaction and reduce the steady state error.
- Integral item may be used to eliminate the steady state error. The larger the number (Ki, integral tuning constant), the larger the integral contribution to the output. When there is steady state error, adjust the “Ki” larger to decrease the error.
  When the “Ki” = 0, the integral item makes no contribution to the output.
  For ex, if the reset time is 6 minutes, Ki=100/6=17；if the integral time is 5 minutes, Ki=100/5=20.
- Derivative item may be used to make the process smoother and not too over shoot. The larger the number (Td, derivative tuning constant), the larger the derivative contribution to the output. When there is too over shoot, adjust the “Td” larger to decrease the amount of over shoot.
  When the “Td” = 0, the derivative item makes no contribution to the output.
  For ex, if the rate time is 1 minute, then the Td = 100; if the rate time is 2 minutes, then the Td = 200.
- Properly adjust the PID parameters can obtain an excellent result for loop control.

Instruction description

- When control input "A/M"=0, it performs manual control and will not execute the PID calculation. Directly fill the output value into the output register (OR) to control the loop operation.
- When control input "A/M"=1, it defines the auto mode of loop control; the output of the loop operation is loaded by the PID instruction every time it is solved. It is equal to Mn (control loop output) in the digital approximation equation.
- When control input "BUM"=1, it defines bumpless transfer while the loop operation changing from manual into auto mode.
- When control input "A/M"=1, and direction input "D/R"=1, it defines the direct control for loop operation; it means the output increases as error increases
- When control input "A/M"=1, and direction input "D/R"=0, it defines the reverse control for loop operation; it means the output decreases as error increases
- When comes the error setting of loop setting points or loop parameters, the PID operation will not be performed and the output indication "ERR" will be ON
- While the engineering value of the controlling process is greater than or equal to the user set High Limit, the output indication "HAL" will be ON regardless of "A/M" state.
- While the engineering value of the controlling process is less than or equal to the user set Low Limit, the output indication "LAL" will be ON regardless of "A/M" state.

- **Description of operand Ts：**
  - Ts：It defines the solution interval between PID calculations, the unit is in 0.01 sec; this term may be constant or variable data.
- **Description of operand SR (Loop setting registers)：**
  - SR+0 = Scaled Process Variable：This register is loaded by the PID instruction every time it gets solved. A linear scaling is done on SR+6 using the high and low engineering range found in SR+4 and SR+5.
  - SR+1 = Setpoint (SP) ：The user must load this register with the desired setpoint the loop should control at. The setpoint is entered in engineering units, it must be the range：LER ≦ SP ≦ HER
  - SR+2 = High Alarm Limit (HAL)： The user must load this register with the value at which the process variable should be alarmed as a high alarm (above the setpoint). This value is entered as the actual alarm point in engineering units and it must be the range：LER ≦ LAL < HAL ≦ HER
  - SR+3 = Low Alarm Limit (LAL)： The user must load this register with the value at which the process variable should be alarmed as a low alarm (below the setpoint). This value is entered as the actual alarm point in engineering units and it must be the range：LER ≦ LAL < HAL ≦ HER
  - SR+4 = High Engineering Range (HER)： The user must load this register with the highest value for which the measurement device is spanned. (For example a thermocouple might be spanned for 0 to 500 degrees centigrade, resulting in a 0 to 10V analog input to the FBs-PLC (0V=0℃, 10V=500℃); the high engineering range is 500, this is the value entered into SR+4.)

    The high engineering range must be：–9999 < HER ≦ 19999
  - SR+5 = Low Engineering Range (LER)：The user must load this register with the lowest value for which the measurement device is spanned.

    The low engineering range must be：–9999 ≦ LER ≦ LAL < HAL ≦ HER
  - SR+6 = Raw Analog Measurement (RAM)：The user's program must load this register with the process variable (measurement). It is the value that the content of analog input register（R3840～R3903）is added by the offset if necessary. It must be the range：0 ≦ RAM ≦ 16380 if the analog input is 14-bit format but valid 12-bit resolution, and 0 ≦ RAM ≦ 16383 if the analog input is 14-bit format and valid 14-bit resolution.

    The resolution of analog input can be defined by register D4004,

    D4004=0, it means 14-bit format but valid 12-bit resolution ; D4004=1, it means 14-bit format and valid 14-bit resolution.
  - SR+7 = Offset of Process Variable (OPV)：The user must load this register with the value as described follows: OPV must be 0 if the raw analog signal and the measurement span of the analog input module are all 0～20mA, there is no loss of the measurement resolution; OPV must be 3276 if the raw analog signal is 4～20mA but the measurement span of the analog input module is 0～20mA, there will have few loss of the measurement resolution（16383×4 / 20 = 3276）.

    It must be the range： 0 ≦ OPV < 16383
  - When the setting mentioned above comes error, it will not perform PID operation and the output indication "ERR" will be ON.
- **Description of operand OR：**
  - OR：Output register, this register is loaded directly by the user while the loop in manual operation mode. While the loop in auto operation mode, this register is loaded by the PID instruction every time it is solved. It is equal to Mn (control loop output) in the digital approximation equation. It must be the range：0 ≦ OR ≦ 16383

- **Description of operand PR (Loop parameters)：**

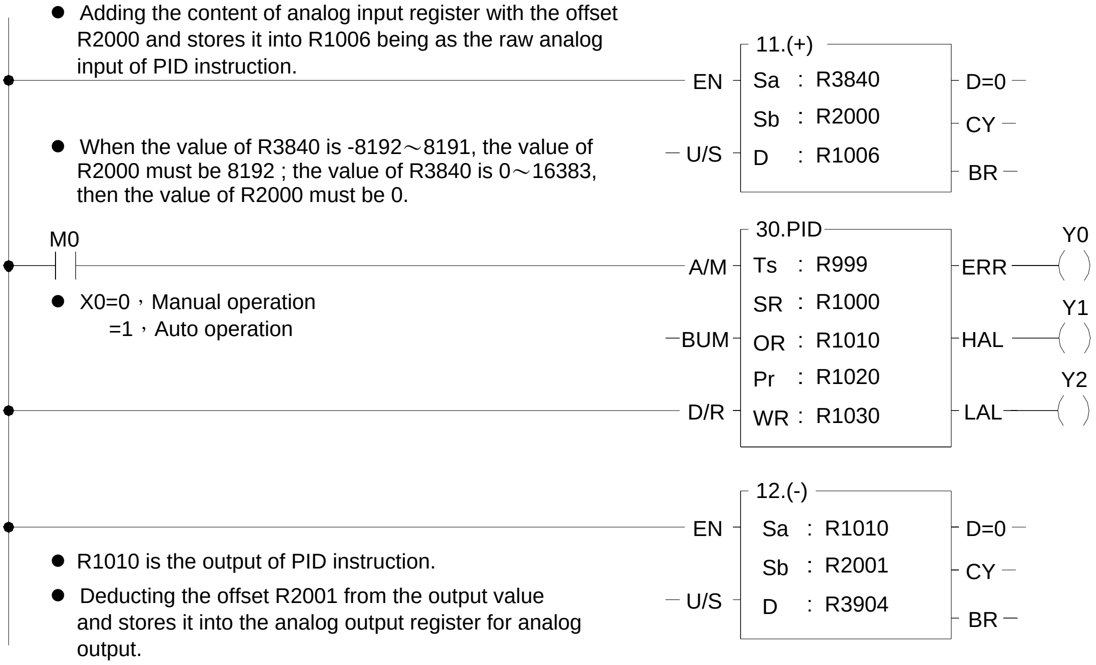
  - PR+0 = Proportional Band (Pb)：The user must load this register with the desired proportional constant. The proportion constant is entered as a value between 1 and 5000 where the smaller the number, the larger the proportional contribution.
    (This is because the equation uses D4005 divided by Pb.)
    It must be the range：1 ≦ Pb ≦5000, unit is in 0.1%
    Kc(gain)=D4005/ Pb; the default of D4005 is 1000, and it's range is 1 ≦ D4005 ≦5000.
  - PR+1 = Integral tuning Constant (Ki)：The user may load this register to add integral action to the calculation. The value entered is "Repeats/Minute" and is entered as a number between 0 and 9999. (The actual range is 00.00 to 99.99 Repeats/Minute.) The larger the number, the larger the integral contribution to the output.
    It must be the range：0 ≦ Ki ≦ 9999 (0.00～99.99 Repeats/Minute)
  - PR+2 = Rate Time Constant (Td)：The user may load this register to add derivative action to the calculation. The value is entered as minutes and entered as a number between 0 and 9999. (The actual range is 0.00 to 99.99 minutes.) The larger the number, the larger the derivative contribution to the output.
    It must be the range：0 ≦ Td ≦ 9999 (0.00～99.99 Minutes)
  - PR+3 = Bias：The user may load this register if a bias is desired to be added to the output when using PI or PID control. A bias must be used when running proportional only control. The bias is entered as a value between 0 and 16383 and is added directly to the calculated output. Bias is not required for most applications and may be left at 0.
    It must be the range：0 ≦ Bias ≦ 16383
  - PR+4 = High Integral Wind_up Limit (HIWL)：The user must load this register with the output value, (1 to 16383), at which the loop shoud go into "anti-reset wind-up" mode. Anti-reset wind-up consists of solving the digital approximation for the integral value. For most applications this should be set to 16383.
    It must be the range：1 ≦ HIWL ≦ 16383
  - PR+5 = Low Integral Wind_up Limit (LIWL)：The user must load this register with the output value, (0 to 16383), at which the loop shoud go into "anti-reset wind-up" mode. It functions in the same manner as PR+4. For most applications this should be set to 0.
    It must be the range：0 ≦ LIWL ≦ 16383
  - PR+6 = PID Method：
    =0 , Standard PID method;
    =1 , Minimum Overshoot Method;
    Method 0 is prefer because most applications using PI control (Td=0).
    The user may try method 1 when using PID control and the result is not stable.

  - When the setting mentioned above comes error, it will not perform PID operation and the output indication "ERR" will be ON.

- **Description of operand WR (Working registers)：**
  - WR+0 = Loop status register：

    Bit0 =0 , Manual operation mode
    =1 , Auto mode
    Bit1 : This bit will be a 1 during the scan the solution is being solved, and it is ON for a scan time.
    Bit2=1 , Bumpless transfer
    Bit4 : The status of "ERR" indication
    Bit5 : The status of "HAL" indication
    Bit6 : The status of "LAL" indication
  - WR+1 = Loop timer register：This register stores the cyclic timer reading from the system's 1ms cyclic timer each time the loop is solved. The elapsed time is calculated by calculating the difference between the current reading of the system's 1ms cyclic timer and the value stored in this register. This difference is compared to 10× the solution interval. If the difference is greater than or equal to the solution interval, the loop should be solved this scan.
  - WR+2 = Low order integral summation：This register stores the low order 16 bits of the 32-bit sum created by the integral term.
  - WR+3 = High order integral summation：This register stores the high order 16 bits of the 32-bit sum created by the integral term.
  - WR+4 = Process variable - previous solution：The raw analog input (Register SR+6) at the time the loop was last sovled. This is used for the derivative control mode.

Program example



- Adding the content of analog input register with the offset R2000 and stores it into R1006 being as the raw analog input of PID instruction.
- When the value of R3840 is -8192～8191, the value of R2000 must be 8192 ; the value of R3840 is 0～16383, then the value of R2000 must be 0.
- X0=0，Manual operation
  =1，Auto operation
- R1010 is the output of PID instruction.
- Deducting the offset R2001 from the output value and stores it into the analog output register for analog output.
- If the output value of R3904 is 0～16383, the value of R2001 must be 0 ; If the value of R3904 is -8192～8191, the value of R2001 must be 8192.

R999 ：The setting of solution interval between calculations; for example the content of R999 is 200, it means it will perform this PID operation every 2 seconds.

R1000：Scaled process variable, which is the engineering unit loaded by the PID instruction every time it gets solved. A linear scaling is done on R1006 using the high and low engineering range found in R1004 and R1005.

R1001：Setpoint, it is the desired value the loop should control at; which is entered in engineering unit. For example the span of controlling process is 0°C～500°C, the setting of R1001 is equal to 100, it means the desired result is at 100°C.

R1002：The setting of high alarm limit; which is entered in engineering unit.
The example mentioned above, if the setting of R1002 is equal to 105, it means there will have the high alarm while the loop is greater than or equal to 105°C.

R1003：The setting of low alarm limit; which is entered in engineering unit. The example mentioned, if the setting of R1003 is equal to 95, it means there will have the low alarm while the loop is less than or equal to 95°C.

R1004：The setting of high engineering range. The example mentioned, if the setting of R1004 is equal to 500, it means the highest value of this loop is 500°C.

R1005：The setting of low engineering range. The example mentioned, if the setting of R1005 is equal to 0, it means the lowest value of this loop is 0°C.

R1006：Raw analog measurement; it is the value that the content of analog input register (R3840～R3903) is added by the offset of 2048.

R1007：Offset of process variable; let it be 0 if the raw analog signal and the span of the analog input module are all 0～10V.

R1020：The setting of proportional band; for example the content of R1020 is 20, it means the proportional band is 2.0% and the gain is 50.

R1021：The setting of integral tuning constant; for example the content of R1021 is 17, it means the reset time is 6 minutes (100/6≒17).

R1022：The setting of derivative tuning constant; for example the content of R1022 is 0, it means PI control.

R1023：The setting of the bias to the output; most applications let it be 0.

R1024：The setting of high integral wind-up; most applications let it be 16383.

R1025：The setting of low integral wind-up; most applications let it be 0.

R1026：The setting of PID method; most applications let it be 0.

R1030 = Loop status register

Bit0 =0, Manual operation mode
=1, Auto operation mode

Bit1 : This bit will be a 1 during the scan the solution is being solved, and it is ON for a scan time.

Bit2=1 , Bumpless transfer

Bit4 : The status of "ERR" indication

Bit5 : The status of "HAL" indication

Bit6 : The status of "LAL" indication

R1031～R1034: They are the working registers, please refer to the description of operand WR.