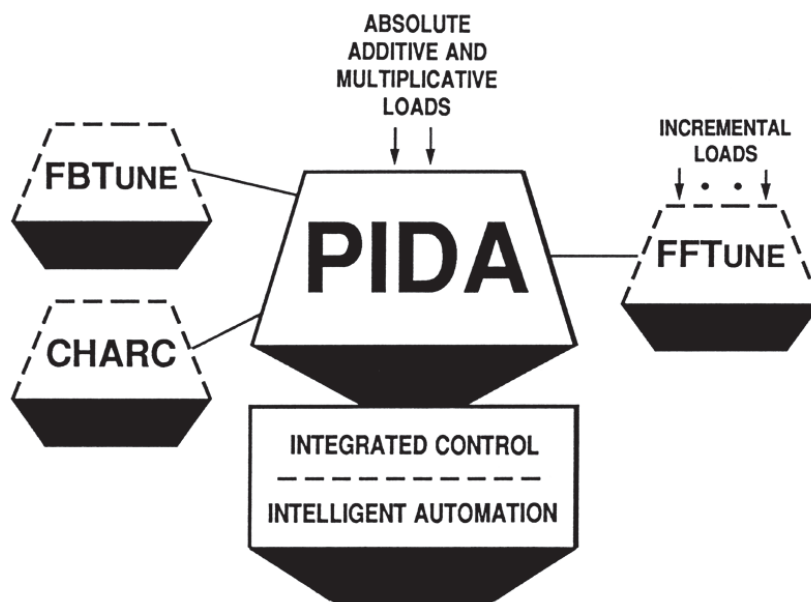


Adaptive Feedback and Feedforward Controller (PIDA)



The PIDA block provides PID or dead-time feedback and absolute feedforward control actions. The FBTUNE extender block adaptively tunes the feedback controller parameters for most PID and dead-time modes. The FFTUNE extender block provides dynamic compensation for an absolute multiplicative or additive feedforward input and both static and dynamic compensations for 3 or 4 incremental feedforward inputs and adapts the compensator parameters. The CHARC characterizer block provides matched non-linear functions to both setpoint and measurement.

FEEDBACK TUNING

The feedback adaptation, provided by the FBTUNE extender block (PSS 31S-3FBTUNE), includes both a pretune function and an ongoing adaptation of the associated PIDA feedback controller tuning (Figure 1). The pretune function provides easy, foolproof commissioning. Working on the principal of model identification, it fits an appropriate model to the process and uses an algebraic tuning method to

establish initial tuning of the loop. If desired, the user may select a model structure to influence the tuning for either a more robust and stable operation, or faster control loop performance.

The on-going adaptation is activated when the control-error reaches a user-set threshold. At that instant, the most appropriate of six sets of stored tuning constants is selected and later updated depending upon the error response pattern.

Error (or controller output) pattern features are used to retune the selected tuning set either indirectly, to partially re-identify the process model, or directly, as input to a tabularly stored function evaluation (using a form of embedded fuzzy logic). The effect of process operating condition changes are anticipated by gain-

scheduling (selecting one of the tuning sets) with the gain-schedule determined adaptively. Use of output peaks for returning may allow detection and correction of an incipient instability before significant control error becomes apparent.

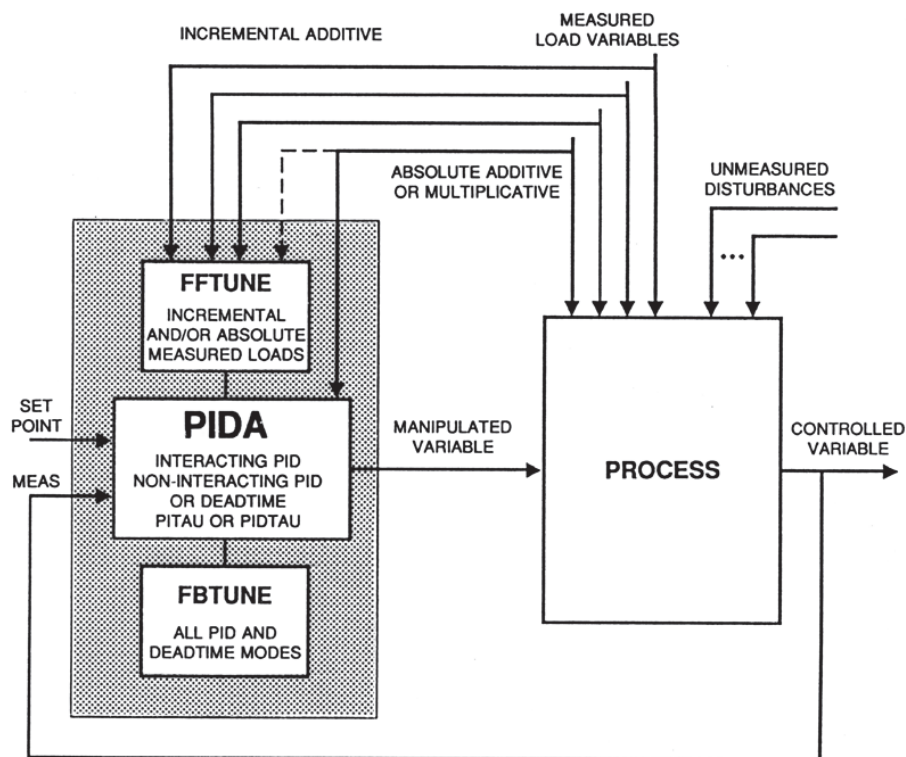


Figure 1. PIDA Adaptive Feedback and Feedforward Controller

FEEDFORWARD TUNING

The FFTUNE extender block (PSS 31S-3FFTUNE) performs both feedforward compensation and adaptation of the compensators. The feedforward controller anticipates the effect of measured loads and the control output on the controlled measurement, taking action at the controller output to minimize the effect of load change on control error. Six sets of compensator tunings are stored. The most appropriate set is selected when a measured load change is detected. Retuning of that compensator coefficient set will occur provided that

the peak error response is sufficiently large and that the error settles within a noise band in an allotted (process dependent) time.

The compensators are gain-scheduled to anticipate the effect of current conditions and the gain-schedule is determined adaptively. This adapted feed-forward capability can be used to partially decouple interacting loops by treating the disturbing loop's manipulations as load input.

PIDA FEATURES

The PIDA contains the features included in the PIDX plus (see PIDA Structure, Figure 2):

- ▶ *Local Setpoint Ramping and Limiting*
The local setpoint can be ramped to a new target value at a user set rate by toggling a switch. Ramping stops when the setpoint reaches the target or when the controller is placed in manual.
- ▶ *Local Setpoint Ramp Time and Limiting*
The local setpoint can be ramped to a new target value at a user-specified ramp time instead of ramp rate. Ramping stops when the setpoint reaches the target or when the controller is placed in manual.

▶ Setpoint Filtering

In the PI and PID modes, an additional parameter is provided to allow the controller to be tuned for both good unmeasured load rejection and good setpoint response. A setpoint filter effectively applies a fraction of the proportional action to setpoint. Optimal tuning of this parameter depends on the process type and is adaptively tuned by FBTUNE.

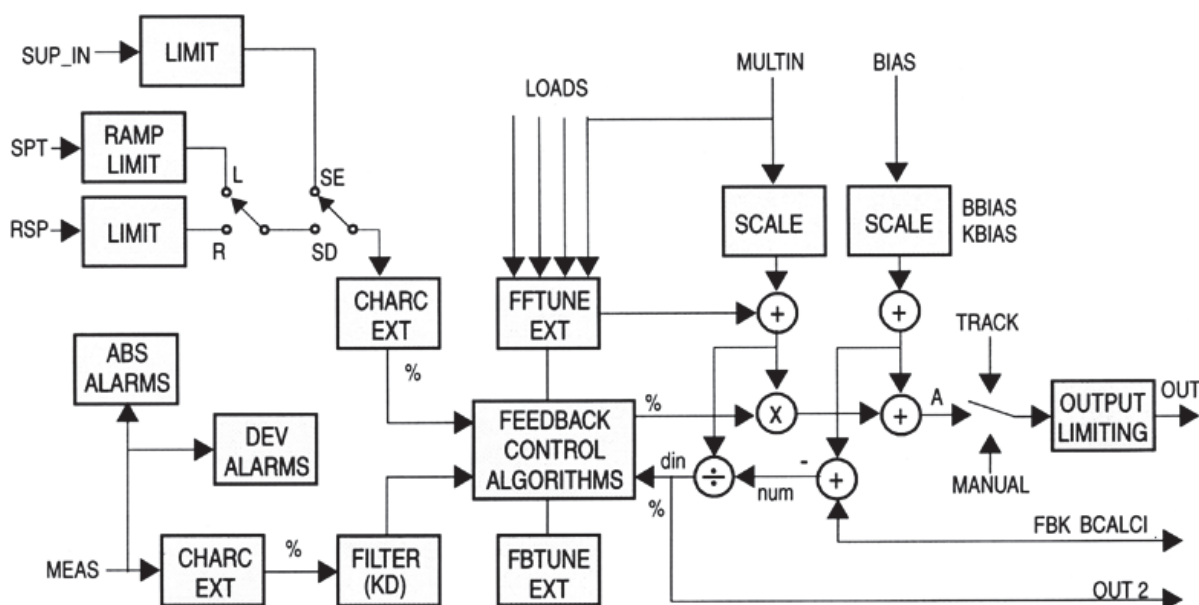


Figure 2. PIDA Structure

- ▶ *Measurement Filtering*
Second order low-pass Butterworth filtering is applied to the measurement in order to prevent excessive controller output activity. The filter can also be used to help stabilize a process with a lightly-damped high-frequency resonance.
- ▶ *Absolute (Multiplicative and Additive) Feedforwards*
The internal feedback controller output is multiplied by a scaled multiplicative input and then added to a scaled additive input, thus combining the feedback controller with a ratio and bias function in the same block. The FBTUNE

block will provide dynamic compensation for either of these absolute feedforward terms. Multiplicative feedforward compensation for a load flow is commonly used in a composition or temperature control loop. Additive compensation for a load flow is commonly used in a level or pressure control loop.

► *Non-Linear Compensation*

Matched non-linear functions can be applied to setpoint and measurement using the CHARC characterizer extender block. In a pH loop, measurement and setpoint can be expressed in pH units while the controller output responds to ion concentration differences.

As in the PIDX, a three-segment function allows gain reduction to be applied to small errors, where uncontrollable high frequency noise may dominate, while not compromising the response to a large control error.

► *New Controller Modes*

The PIDA contains the P, I, PD, PI, PID (interactive) controller modes contained in the PID and PIDX blocks. In addition, the PIDA contains NIPID (non-interacting PID), PITAU (interacting PID dead-time), and PIDTAU (non-interacting PID dead-time). All except P, I, and PD are adaptively tuned by the FBTUNE extender block.

Non-interacting PID is capable of outperforming an interacting PID or PI when the process has a secondary lag greater than twice the process dead-time.

The dead-time controllers PITAU and PIDTAU behave similarly to a Smith Predictor for a dominant dead-time process. However, if the process contains a lag larger than the dead-time, the PIDTAU can be tuned more tightly so that it outperforms the Smith Predictor and non-interacting PID. However, compared with a PID, PITAU and PIDTAU are less robust.

NON-INTERACTING VS. INTERACTING CONTROL ACTION

When both derivative and integral actions are applied to the controlled measurement, the algorithm can be structured as either a product of factors (interacting)

$$\frac{100}{P_I s} \left(\frac{1}{I_I s} + 1 \right) (1 + D_I s)$$

or as a sum of terms (non-interacting)

$$\frac{100}{P_n} \left(\frac{1}{I_n s} + 1 + D_n s \right)$$

where

$$s = \frac{d}{dt}$$

is the differential operator.

The interacting form is the structure traditionally preferred by Foxboro because it enables an integral-feedback input to be used to prevent integral wind-up and tighten cascade-loop tuning. However, the non-interactive form allows tuning where the numerator polynomial in s cannot be factored into two real roots. Such tuning allows improved control for processes containing a secondary lag larger than twice the effective process dead-time. (The effective process dead-time includes the true dead-time plus the sum of tertiary lags minus negative leads.) The PIDA non-interactive modes achieve this advantage and also those of the interacting form resulting from an integral-feedback input.

PID VS. DEAD-TIME CONTROL

A PID controller achieves good unmeasured load rejection and fast recovery from output limiting when it is tuned to have high feedback gain, limited by the need for robust low overshooting performance. To achieve good setpoint tracking tuned for unmeasured load rejection, the PIDA block employs a setpoint filter with one additional tuning parameter whose value ranges from 0.2 for a dominant lag process to 1.0 for a dominant dead-time process. This parameter is adaptively tuned by FBTUNE.

A traditional dead-time controller, such as the Smith Predictor or Dahlin form, uses a model ideally matching the process in the controller feedback. When the controller model matches the process and the only disturbance is due to the manipulated variable (controller output) the model feedback cancels the process feedback. To achieve good setpoint tracking, the controller's forward path should approximate the inverse of the invertible part of the process. As a result, the controller's forward path has high gain at high frequencies where the process gain is low and possibly low gain at low frequencies where the process gain may be high. Such a dead-time controller applied to a process with a primary lag larger than 1.5 times the effective dead-time will provide poorer unmeasured load rejection than a well-tuned PID.

To avoid explicitly splitting the traditional dead-time controller's process model into its invertible and non-invertible factors and to assure prompt recovery from output limiting (constraint enforcement), the controller forward path may be implemented as an output trajectory optimizer. The output trajectory is reoptimized each output update interval. This computationally intensive optimization may require an unusually large output update interval, adding significant effective dead-time to the process dead-time, thereby further compromising the achievable performance.

The FBTUNE extender block deliberately mismatches the PITAU or PIDTAU feedback model from the process in order to achieve good unmeasured load rejection and prompt recovery from output limiting.

$$PITAU: \frac{100(1 + I_s)(1 + D_s)}{P \quad I_s + 1 - e^{-\gamma s}}$$

$$PIDTAU: \frac{100 \frac{1 + D_s + ID_s^2}{P \quad I_s + 1 - e^{-\gamma s}}}$$

The primary model lag is made much smaller than a dominant process lag, causing the PIDA dead-time controller to have much higher gain than a traditional dead-time controller at low frequencies. This tuning strategy eliminates the need for controller output trajectory optimization, thereby allowing a small output update period compared with the process dead-time. The adaptively tuned PIDTAU mode will provide tighter control compared with the adaptively tuned non-interactive PID mode on many processes. The improvement may be as much as a factor of two in integrated absolute error in rejecting unmeasured loads and setpoint tracking. However, performance degrades rapidly if the process changes.

Because FBTUNE adaptively tracks a changing process, it is usually not necessary to employ detuning filters or other measures to provide adequate robustness.

The PITAU or PI mode should be selected when the process has a dominant dead-time or when measurement noise would make derivative action undesirable.

Supervisory Control

Supervisory Control (SSC) allows a user's application program to perform supervisory control over the PIDA block's setpoint. SSC can be enabled/disabled by an operator, or enabled by the supervisory application program at a control block group or control block level. If SSC is enabled in the control block, the back calculated value status requests the application program initialization. The application program must send the supervisory setpoint to the block periodically. While SSC is enabled, the control block parameters associated with local setpoint are not settable by the operator. If the operator asserts fallback or if a supervisory application program failure is detected, the control block falls back to a configured fallback mode (Manual, Auto, Remote, or Local).

PID Control Functions

The PID control functions of the PIDA block include those in the standard PIDX block and can be configured to operate in one of the following controller modes:

- ▶ Proportional (P)
- ▶ Integral (I)
- ▶ Proportional-plus-Derivative (PD)
- ▶ Proportional-plus-Integral (PI)
- ▶ Proportional-plus-Integral-plus-Derivative (PID)
- ▶ Non-interactive PID (NIPID)
- ▶ Interactive dead-time (PITAU)
- ▶ Non-interactive dead-time (PIDTAU)

Standard PID Features

- ▶ Manual/Auto control of the output, which can be initiated by either a host process or another block.
- ▶ Local/Remote setpoint source selection.
- ▶ Enhanced measurement filtering for improved controller performance.
- ▶ Adjustable measurement filter time constant in relation to derivative or dead-time.
- ▶ External integral feedback and logic signals to prevent windup during closed-loop operation.
- ▶ Assignable engineering range and units to measurement, bias, multi-in and output.
- ▶ Automatic scaling, based on assigned engineering ranges, so that the proportional band is expressed in percent.
- ▶ Output biasing with scaling.
- ▶ Output clamping between variable output limits.
- ▶ Bad inputs detection and handling.
- ▶ Bumpless transfer of the output signal when the block returns to controlling operation in Auto, which is inherent in all controller modes.
- ▶ Fast reaction to manual output change.
- ▶ Automatic cascade handling that includes:
 - ▶ Explicit initialization input/output parameters that provide proper coordination and fast initialization of cascade schemes.

Extended Options

- ▶ Nonlinear gain compensation
- ▶ Variable or triggerable update interval
- ▶ Batch control, with preloadable integral
- ▶ Output tracking

PID Options

- ▶ Setpoint tracking of the measurement signal allows bumpless return to automatic control when the block or any downstream block returns to normal operation.
- ▶ Manual override forces the block to Manual if either the measurement or feedback inputs are off scan, disconnected, or bad. Return to automatic control requires external intervention.
- ▶ Absolute alarming of the measurement.
- ▶ Deviation alarming of the setpoint — measurement error signal.
- ▶ Absolute alarming of the output.
- ▶ Manual alarming allows all configured alarm options to be operational in Manual.
- ▶ Reverse action: measurement increases cause controller output to increase.
- ▶ Output clamping when block is in Manual.
- ▶ Bias tracking forces bias to track the output when block is in Manual. Operational only in the P and PD controller modes
- ▶ Three anti-windup strategies for recovering from downstream limiting.
- ▶ Linear scaling of BIAS parameter.
- ▶ Workstation lock access allows write access to only the Display Manager which owns the lock.
- ▶ Loop identifier allows the user to identify the loop or process unit that contains the block.
- ▶ Supervisory Control (SSC) of the block's setpoint.

Additional Features

- ▶ Delayed alarming. A configurable timer delays alarm detection or return-to-normal messages for a specific alarm to reduce the number of alarm messages generated when a block parameter crosses back and forth over an alarm limit.
- ▶ Quality Status output parameter provides a single source for the block's value record status, block status, and alarm status.



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