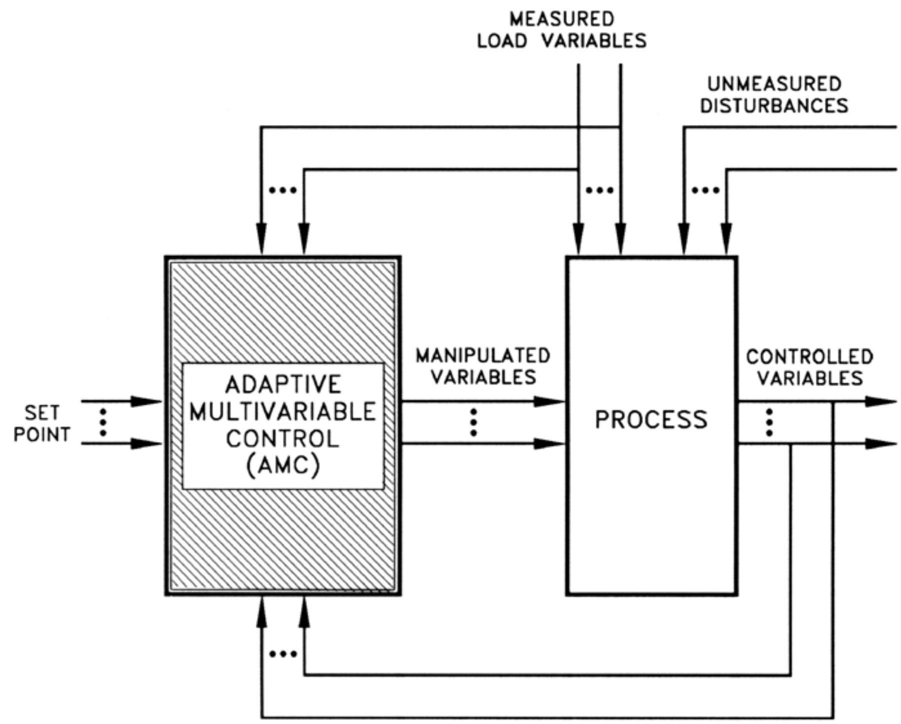
I/A Series® Software
EXACT Multivariable Control (EXACT® MV)



The I/A Series EXACT Multivariable Controller provides innovative technology specifically designed to control processes with variable gains and dynamics, multivariable interactions, measured load upsets, and unmeasured disturbances. With its robust adaptive technology, EXACT MV automatically adjusts to the gains and dynamics of the process, and thus, achieves closer control to set points.

OVERVIEW

The I/A Series EXACT Multivariable Controller with Adaptive Multivariable Control is easily applied by control engineers familiar with PID technology. It provides feedforward tuning of up to four variables, plus tuning of the feedback controller. On the low end, it provides superior control of a single difficult to control loop with multiple load upsets. On the high end, multiple blocks can interconnect interactive signals among the loops to improve control for up to five interacting control loops in a five by five cross coupled scheme.

EXACT MV technology is provided by a family of three new I/A Series control blocks. At the core is a new advanced control block, PIDA, for advanced PID control (PSS 21S-3M2 B4). However, the formula for adaptive multivariable capability resides in the new feedback tuning extender block, FBTUNE (PSS 21S-3L3 B4), and the new feed-forward tuning block, FFTUNE (PSS 21S-3L4 B4).

In process control loops the longer the deadtime, and the greater the deadtime-to-lag ratio, the more difficult it is to maintain the controlled variable close to its desired set point. The controlled variable deviation from set point is even more pronounced when the load variables change often and their change is large. Improved control can be achieved using feedforward techniques (FFTUNE).

The difficulty of precise control is further complicated by both dynamic elements and multi-loop interactions. In a continuous process, the load and manipulated variables typically have a time difference between them, since their measurements occur at different points within the process flow. The traditional method of compensating for these dynamic elements is to use a combination of lags, leads, and deadtimes in the feedforward scheme. However, traditional feedforward schemes do not compensate for unmeasured load variables, process nonlinearities, and dynamic timing shifts resulting from changes to process throughput.

The traditional method of control in a multivariable interactive process is to pair controlled variables to manipulated variables with multiple single loop controls. However, controlling these variables independently does not account for the interaction between them in a process. The controllers only respond to the interaction through their feedback response, as if the interaction was a load upset. The result is non-optimal control and possibly unstable behavior.

EXACT MV controls these situations by providing adaptive feedforward tuning of up to four load or interactive variables. It automatically adapts the gain and dynamics of each feedforward variable while at the same time the feedback action of the controlled variable is adaptively tuned to the dynamic changes of the process.

With this technique, EXACT MV control provides automatic calibration of the feedforward compensation elements and recalibration when a significant shift in process dynamics is detected.

PERSPECTIVE

Recent years have seen a proliferation of new control technology aimed at optimization of plant performance and closer control. Self-tuning controllers were introduced in the mid 1980s to improve upon the job humans could do in properly tuning control loops, or at least relieve the tedium of doing so. Fuzzy logic technology has been embedded within controllers, and used as an engineer's tool to improve or automate tuning, reduce response overshoot or hunting, or interpolate rules to handle control systems with multiple interacting variables.

Multivariable model predictive control systems have also been introduced as a model based control technique for processes where numerous variables interact.

All of these technologies have their place. However, successful and practical application of advanced control products must meet several criteria. The products must be sufficiently easy to understand and apply by the engineering team. To keep running throughout the life of the plant, the products must be adequately robust to deal with dynamic changes to the process, throughput changes, product grade changes, operator set point changes, and more. As a practical matter, there are too many cases where these systems have fallen into disuse, or even been decommissioned, as a result of lack of maintenance on the application, or a misunderstanding of how it should be applied. Many of these existing technologies require extensive engineering, testing, and commissioning time to function properly. For some products, poor performance can result when set points or throughput of the process are changed, unless the system is recalibrated and retuned for the new operating conditions.

Benefits of Adaptive Multivariable Control

Considering the above perspective, the benefits of the EXACT MV as provided by the PIDA, FBTUNE, and FFTUNE blocks are:

- EXACT MV provides robust adaptive technology that automatically adjusts to the gains and dynamics of the process, and thus, achieves closer control to set points.
- EXACT MV provides innovative technology specifically designed to control processes with variable gains and dynamics, multivariable interactions, measured load upsets, and unmeasured disturbances. FBTUNE and FFTUNE not only adapt but, they also learn. Adapted tuning are gain scheduled to anticipate non-linear effects.
- Being more robust than other adaptive controllers, EXACT MV can be used in a wide range of applications, from simple ratio control with feedback trim to multiple interacting loops with feedforward additive or multiplicative compensation for measured load and interactive variables and linear and non-linear feedback compensation for constraint handling and unmeasured disturbances.

- EXACT MV provides faster and higher gain feedback for processes with lags greater than the deadtime. This results in improved unmeasured disturbance rejection resulting in tighter control as compared to other model-based deadtime controllers, such as the Smith Predictor, Dahlin, Model Predictive Control, and others. Furthermore, EXACT MV does not require detuning to achieve robustness since it adapts to process changes.
- EXACT MV lends itself easily to cascade connections and to upper level optimization software packages, such as non-linear and linear programming and others.
- Set point compensation for the controller provides good set point response for optimum load rejection tuning.
- Being implemented in control blocks, EXACT MV inherits all block benefits such as:
  – All standard and extended control block features and options, such as a number of different controller modes, alarming, limiting.
  – The control and adaptive algorithms are designed to be insensitive to sample interval, and therefore, the sample interval can be very short or relatively long.
  – Easy configuration and implementation using standard control block methods.
  – Easy and consistent operator displays as with other control blocks.
  – Running rapidly and securely in the Control Processor environment as do other control blocks.
  – Easy, consistent, and fast initialization, constraint handling, and controller mode changes.
  – Easy and consistent maintenance.
  – Easy and consistent interface with other control blocks.

INTERACTING MULTIVARIABLE LOOP EXAMPLE WITH FEEDFORWARD

An example of Adaptive Multivariable Control applied to an interacting multivariable process simulation is shown in Figure 1. The simulation consists of two interactive loops, the top slower loop (PIDA 1) and the lower faster loop (PIDA 2). Each loop has one feedforward measured load and one unmeasured load. The dynamics in its interactive path from the PIDA 2 controller output are twice as slow as compared to those in the interactive path from PIDA 1 to the bottom loop.

The measurement, set point, and output responses of each (PIDA 1, PIDA 2) controller are shown in Figure 2.

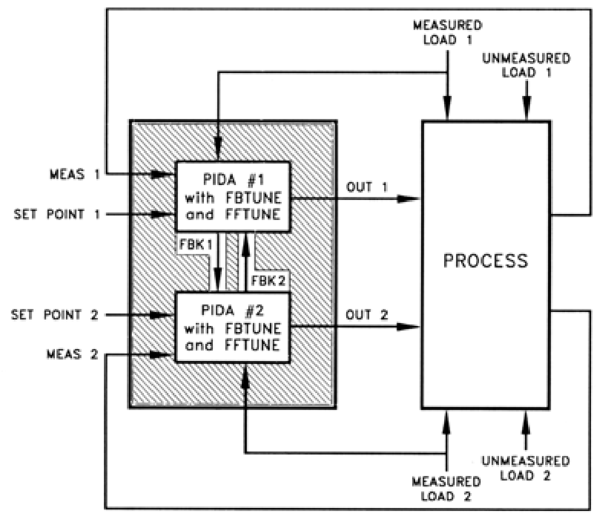


Figure 1. EXACT MV Compensation for Interactive Loops and Measured Loads

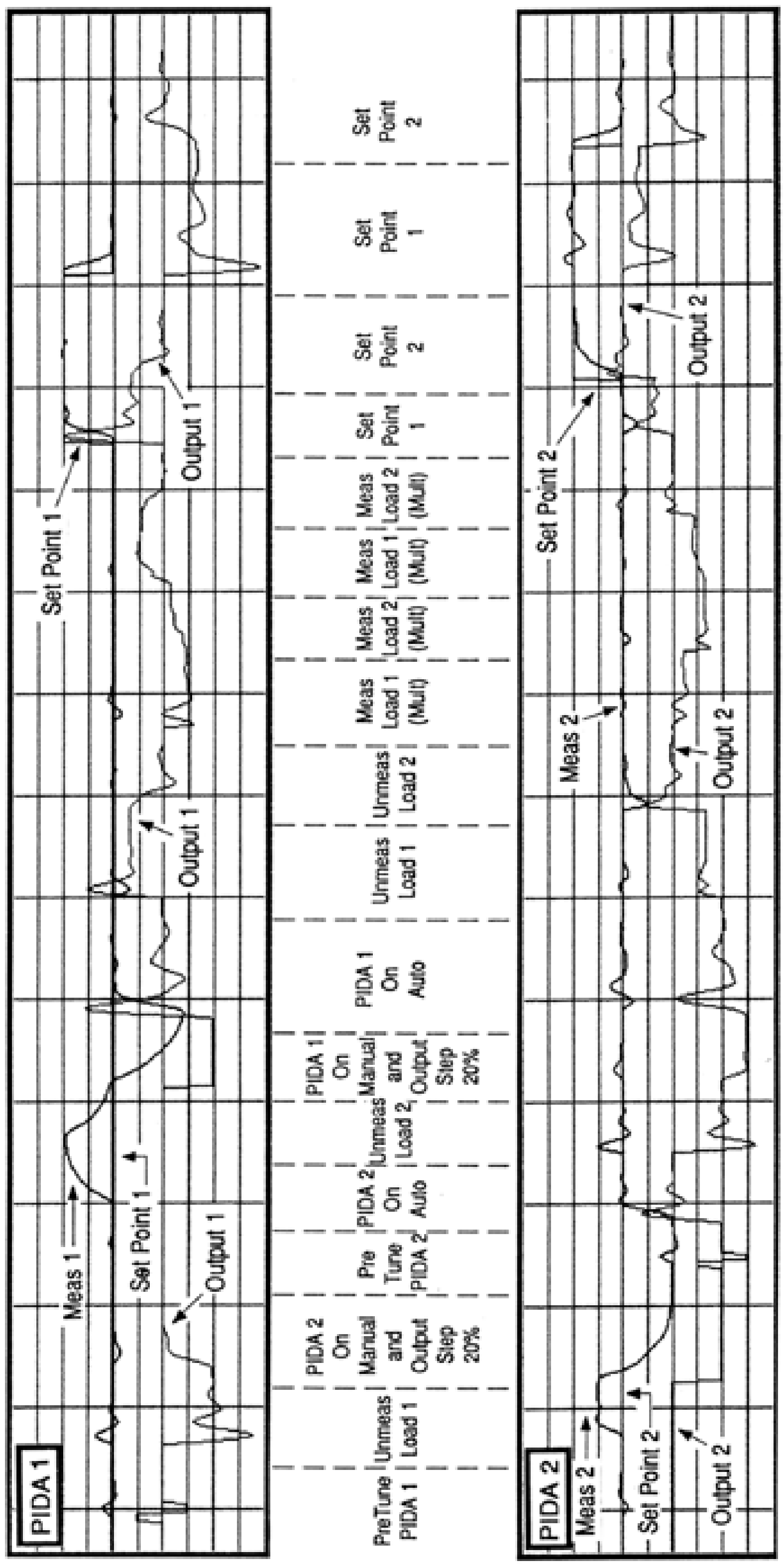


Figure 2. EXACT MV Response for Interacting Loops and Measured Loads

Pretune and Feedback and Feedforward Self-Tune for the Slower Loop PIDA 1 Compensating for Interaction

The experiment is initiated with the PIDA 1 controller on manual with its pretune "ON" and its feedforward self-tune "ON"; the PIDA 2 controller on manual with its output at 40%, its pretune "OFF" and its feedforward self-tune "OFF".

The upper beginning part of Figure 2 shows the pretune response of PIDA 1. When pretune is completed, PIDA 1 is placed in “AUTO”.

Feedback self-tune of PIDA 1 is initiated by making a 20% step change to Unmeasured Load 1. Upon completion of this upset, the feedback settings of PIDA 1 are tuned. PIDA 1 is now ready to be tuned for the feedforward compensation of the interaction from PIDA 2.

The interaction is compensated by connecting the feedback signal FBK2 from PIDA 2 to an incremental additive feedforward input of FFTUNE.

The feedback signal as opposed to controller output is used because it is computed based on the effective manipulated variable as compared to its requested value. This accounts for constraints and/or mode changes of downstream controllers.

Feedforward self-tune is initiated by making a 20% step change to the manual output of controller PIDA 2 as shown in Figure 2. Upon completion of this upset response, the feedforward self-tune obtains the gain and dynamic parameters that compensate for the interaction from the PIDA 2 controller.

Pretune and Feedback and Feedforward Self-Tune for the Faster Loop (PIDA 2) Compensating for Interaction

Tuning of the faster loop is accomplished by placing the slower PIDA 1 controller, shown in Figure 1, on manual with its output at 40%. Tuning is initiated with the PIDA 2 controller on manual with its pretune “ON” and its feedforward self-tune “ON”.

The pretune response of PIDA 2 is shown in the lower part of Figure 2. When pretune is completed, the PIDA 2 controller is placed in “AUTO”. The controller now drives the measurement to its set point (note, measurement has been away from its set point because the output has been on manual). The response, shown in Figure 2, shows how well the pretune adapts the controller settings to the process.

With pretune completed, feedback self-tune of PIDA 2 is initiated. As a result of the initial response, new parameters for self-tune are set for the controller. A 20% step change is now made to unmeasured load 2 (Figure 1) in order to tune PIDA 2 for load upsets. When the upset response is complete, the feedback settings of the PIDA 2 controller are tuned.

PIDA 2 is now ready to be tuned for the feedforward compensation of the interaction from the PIDA 1 controller. The interaction is compensated by connecting the feedback signal FBK1 from PIDA 1 to an incremental additive feedforward input of FFTUNE.

The feedforward self-tune is initiated by making a 20% step change to the manual output of controller PIDA 1 as shown in top part of Figure 2. When the upset response is complete, feedforward self-tune obtains the gain and dynamic parameters that compensate for the interaction from the PIDA 1 controller. This response shows a single sided effect of the uncompensated interaction, corrected only by feedback. When this action is complete, the PIDA 1 controller is placed on “AUTO” and its measurement is driven to its set point as shown in Figure 2.

The effect of the compensation for interaction is obtained by making a 20% step change in the Unmeasured Load 1 (Figure 1).

The interactive effect of this is shown in the measurement response of PIDA 2. This compensated interaction response is symmetrical and smaller in each direction as compared to the uncompensated interaction response. Loop 1-to-Loop 2 compensation for interaction is now evident.

To demonstrate the effective compensation for interaction from Loop 2-to-Loop 1 obtained by the feedforward compensation of the interactive variable, a 20% step change in unmeasured load 2 is made. Its effect is shown in the measurement response of PIDA 1 in Figure 2.

Multiplicative Feedforward Self-Tune for PIDA 1 and PIDA 2

Compensation for up to three measured load variables can be realized by the feedforward self-tune of each controller in addition to the feedforward compensation for interaction. Figure 1 shows the simulation of one additional multiplicative feedforward, Measured Load 1 and Measured Load 2, for PIDA 1 and PIDA 2, respectively.

With the feedback and feedforward self-tune of the PIDA 1 and PIDA 2 “ON”, a 30% step change was made to measured load 1. Shortly after, a 30% step change was made to measured load 2 with the uncompensated responses shown in Figure 2. These step changes were made in order to self-tune the two feedforward measured load variables.

The remaining two load changes, shown in Figure 2, display the improved results of the feedforward self-tune. While these load upsets were made, the feedback self-tune was computing new tuning parameters for the feedback controllers. In addition, it computed new parameters for the feedforward signals that compensate for the interaction of the two loops.

Set Point Responses for PIDA 1 and PIDA 2 with Feedforward Interaction Compensation

PIDA 1 and PIDA 2 loops are left with both the feedback and feedforward self-tune "ON". Each new upset initiates compensator updates for process gain and dynamics changes for the measured load variables and the loop interaction and a feedback tuning update for an unmeasured load upset and set point change.

The set point responses of both controllers are shown in the final portion of the Figure 2 response curve. To initiate these responses, the set point of PIDA 1 is increased from 60% to 80%, then the same is repeated for PIDA 2. When complete, both set points are set back to 60% sequentially. Note that a set point change in PIDA 1 causes interaction in the PIDA 2 loop and the feedforward compensation responds to minimize it. Similar action is detected with the set point change in PIDA 2. The responses show the effectiveness of the feedforward self-tune for interaction compensation as well as the feedback self-tune.

EXACT MV APPLICATIONS

Simulated results presented here demonstrate that the Adaptive Multivariable Controller can provide effective and beneficial control for a wide variety of process control applications. Loops with large set point changes or load upsets can benefit.

The EXACT MV controller automatically adapts the steady-state and dynamic parameters of measured load variables that are compensated in feedforward fashion as well as adapting the controller settings of the feedback controller.

It has also been demonstrated that by interconnecting the feedback signals of the EXACT MV controllers of interacting loops to the appropriate feedforward inputs, it provides adaptive compensation for the interaction among a number of loops.

In general, EXACT MV can be used in any application where a conventional feedforward system is currently applied.

For example, EXACT MV can be applied to:

- top composition and flow ratio schemes in multi-product distillation control.
- zone dryer control to decouple temperature control between adjacent zones.
- pH control schemes to handle non-linearity and process gain changes resulting from large load swings.
- numerous other applications such as ratio and bias control and others.

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