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Bailey

control systems

Application Guide

AG-0000-953-01

Self-Tuning Control

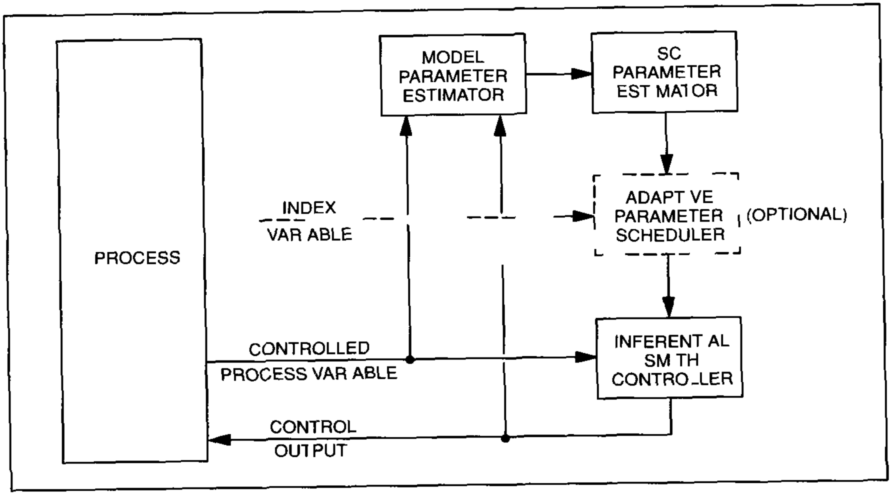

FIGURE 1 Bailey Self Tuning Control

Introduction

Many industrial processes are now required to perform efficiently over a wide range of operating conditions. In many cases these processes and their control systems were initially designed to produce a single product at a single production rate. Current economic conditions often require the same process to produce a variety of products at a variety of production rates. In many cases, the necessary operating efficiencies require major changes in both the process design and the control strategy.

One fundamental problem continues to limit process performance. Conventional process controllers can not effectively control the required variables over a broad range of process operating conditions.

Many techniques address this problem, but only with limited success. Bailey Controls provides a unique self tuning control capability which combines the attributes of many of these techniques, and overcomes the problems associated with each. The most effective elements of modern control theory estimation theory and numerical analysis have been combined with a solid base of process control experience to develop this self tuning control capability. This application guide discusses the self tuning control concepts and implementation of self tuning control in Bailey microprocessor based controllers.

Bailey **Seamless, Real-Time Process Management Solutions**

Summary of Benefits

The Bailey approach to self tuning control offers the following functional benefits:

- Simple commissioning with no user settings required.
- Effective control for processes with a long transport delay (deadtime).
- Elimination of poor controller performance during self tuning for predictable changes in process behavior.
- Optimum controller performance throughout the entire process operating range without manual retuning.
- Design flexibility to accommodate special process characteristics.
- Full integration with standard Bailey control logic functions.

Depending on the application, these functional benefits can often be translated into specific economic benefits.

Bailey Self-Tuning Control

A group of specialized function blocks have been developed to provide self tuning for the Inferential Smith Controller (ISC) algorithm available in Bailey microprocessor based controllers. These function blocks can be configured into the control logic to provide superior control for industrial processes which must perform efficiently over a wide range of operating conditions. The relationship between these specialized function blocks is shown schematically in **Figure 1**.

The Model Parameter Estimator monitors the controlled process variable and control output for the ISC and automatically establishes a first order dynamic model of these variables. The parameters of this dynamic model are automatically translated to the required controller tuning parameters by the ISC Parameter Converter. For processes where ISC tuning parameters are related to other process variables, an Adaptive Parameter Scheduler automatically establishes a statistically valid correlation and adjusts the tuning parameters for the ISC based on this correlation.

Special features have been designed into these function blocks to simplify commissioning and operation of the self tuning Inferential Smith Controller. To commission the controller, only the following user activities are required:

- The process measurement signal(s) must be calibrated, connected and validated.
- The control valve must be connected and its operation verified.
- The process must be operated manually to set the control valve to a nominal operating position (typically 50%).
- The automated initialization routine must be activated and the controller must be set to AUTOMATIC mode. This routine automatically exercises the control valve a preset amount from the manually set valve position to collect information about the process. No manual adjustments are required to initialize the controller. However, this step can be eliminated if sufficient engineering information is available on the process to manually input initial settings for the self tuning function blocks.
- The initial settings can be reviewed after the automated initialization routine has been completed. The controller will be automatically switched to MANUAL mode to provide this opportunity for review. These initial settings can be adjusted manually at this point if desired.
- The controller must be returned to AUTOMATIC mode.

Once the controller is returned to AUTOMATIC mode after the automated initialization routine has been completed, the self tuning algorithm quickly converges to the optimal tuning for the desired controller performance. As the process dynamics change, the dynamic model and the controller tuning parameters are automatically updated to maintain the desired performance.

Each of the specialized self tuning function blocks is discussed briefly below and an example application for self tuning control is presented. A brief discussion of the Inferential Smith Controller function block is also provided.

Inferential Smith Controller (ISC)

The Inferential Smith Controller is a model based control algorithm which has been shown to provide control equivalent to a standard PID algorithm in many applications. However, in applications with significant transport delays (process deadtime), the ISC provides control which is superior to the PID algorithm.

The Inferential Smith Controller utilizes a first order dynamic model with deadtime to predict what the current value of the controlled process variable should be from past values of the control output. A control action is calculated from the difference between the predicted and actual value of the controlled process variable. The magnitude of the required control action is dictated by the parameters of the model. Although many industrial processes are known to be of second or higher order, this first–order model provides an effective representation of these processes for the purpose of regulatory control.

The ISC algorithm provides servo response and disturbance rejection superior to a standard PID algorithm for processes with significant deadtime. Since the Inferential Smith Controller recognizes the dynamic behavior of the process, it inherently paces the control action to the process response capability. This is critical for processes with a significant delay between the time that a control action is initiated and the time that the corresponding effect on the controlled process variable is detectable (transport delay or deadtime). The standard PID algorithm cannot compensate for this deadtime and can easily over react to process upsets and/or setpoint changes, producing process oscillations which are only eliminated by detuning the controller to provide sluggish response.

The desired performance of the Inferential Smith Controller is established by the value of the controller time constant. This value typically ranges from 30% to 300% of the process lag time. The lower setting provides extremely tight control but requires an accurate model of the process. The higher setting provides over damped control which is more robust, allowing significant mismatch between model and actual process behavior. Typical responses of an ISC to a setpoint change for this range of controller time constants is shown in **Figure 2**.

The configuration requirements for the Inferential Smith Controller are identified in **Table 1**. When this function block is used with the ISC Parameter Converter, the value for specifications S7 (Process Gain), S8 (Process Deadtime), S9 (Process Lag Time) and S10 (Controller Time Constant) are provided automatically during the initialization routine and the value of specifications S7 and S9 are periodically adapted as required to optimize controller performance.

Model Parameter Estimator

Without self tuning, the Inferential Smith Controller operates from a fixed model. This model may effectively represent the process at some point in time, but if the process behavior changes significantly, possibly due to a shift in operating point or equipment deterioration, the performance of the ISC (or any other control algorithm) will deteriorate. This deterioration generally has a significant adverse economic impact on process operations.

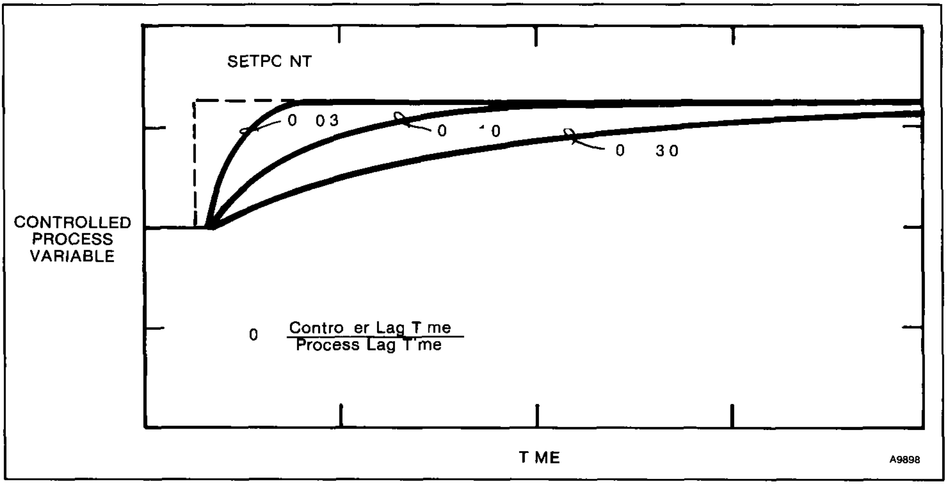

FIGURE 2 Effect of ISC Time Constant on Controller Performance

To compensate for a change in process behavior, the Model Parameter Estimator continuously monitors the dynamic response of the controlled process variable to the control output. The response of the process to the control action provides all of the information necessary to estimate values of the process gain and lag time.

Initial settings for the various Model Parameter Estimator specifications are automatically provided by the ISC Parameter Converter at the conclusion of the automated initialization routine. Once the Model Parameter Estimator has been initialized and the Inferential Smith Controller is returned to AUTOMATIC mode, the Model Parameter Estimator quickly converges on the optimum values for the process model parameters (at the current process operating point) using a specialized recursive least squares technique. As significant changes in process behavior are detected, the dynamic model is automatically updated to reflect these changes.

Several heuristic rules are utilized by the Model Parameter Estimator to maximize the effectiveness of the estimates. The combined effect of these rules is to provide the following functions:

- Deactivation of the estimation algorithm during periods of stable process performance. This prevents long term drift of the model parameter estimates.

- Reinitialization of the estimation algorithm for each significant disturbance or change in process behavior. This accelerates convergence of the model on the new process response data.

The Model Parameter Estimator also continuously assesses the validity of the model parameter estimates using a complex procedure. When the model parameters are determined to be invalid, a New Parameter Estimate in Progress flag is indicated and the estimator attempts to converge to a new estimate. This is a normal occurrence and will occur frequently throughout the operation of the estimator.

The configuration requirements for the Model Parameter Estimator are identified in **Table 2**. Specifications S4 (Sample Time), S5 (Process Deadtime) and S6 (Expected Noise Level of Process) are automatically set during the initialization routine. When the Model Parameter Estimator is used in conjunction with the ISC Parameter converter, specification S5 (Process Deadtime) is not used and the process deadtime is internally updated by the ISC Parameter Converter.

ISC Parameter Converter

The ISC Parameter Converter translates the model parameters determined by the Model Parameter Estimator into the specific tuning parameters required for the Inferential Smith Controller. This function block enforces the allowable range for the tuning parameters and suspends retuning of the controller when either an external logic flag is set or the status New Parameter Estimate in Progress of the model parameter estimates is indicated.

The ISC Parameter Converter also supervises the automated controller initialization routine. When this routine is activated, the ISC Parameter Converter exercises the control output within the established constraints (typically ±5%) from the manually established valve position. Once adequate data has been accumulated to establish initial estimates of the model parameters, the ISC Parameter Converter translates these values to initial values for selected specifications of the Inferential Smith Controller and the Model Parameter Estimator and pulses the ISC control station to MANUAL mode. The automated initialization routine can be interrupted at any time by setting the associated control station to MANUAL mode.

The configuration requirements and functional details of the ISC Parameter Converter are identified in **Table 3**. Specifications S5 (Minimum Allowable Process Gain), S6 (Maximum Allowable Process Gain), S7 (Minimum Allowable Process Lag Time) and S8 (Maximum Allowable Process Lag Time) are automatically established during the initialization routine.

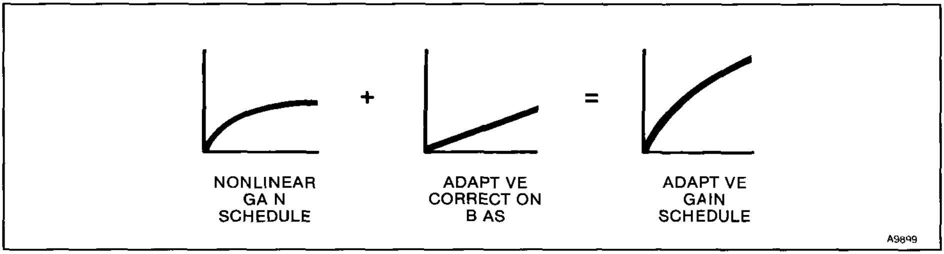

FIGURE 3 On Line Adaptation of an Established Nonlinear Gain Schedule

Adaptive Parameter Scheduler

As the process shifts from one operating point to another, the Inferential Smith Controller will be automatically retuned to maintain the desired controller performance at the new operating point. However during self tuning, ISC performance can be temporarily less than desirable. In applications where the specific value of an ISC tuning parameter (process gain and/or lag time) is related to some process variable or discrete event (an index variable) these periods of sub–optimum controller performance during self tuning can be eliminated by adaptive scheduling of the tuning parameter.

The Adaptive Parameter Scheduler utilizes a least squares technique to automatically correlate a preselected index variable with one controller tuning parameter output by the ISC Parameter Converter. Once an effective linear correlation has been established, the Adaptive Parameter Scheduler adjusts the tuning parameter for the ISC as a function of this index variable. If more than one tuning parameter must be scheduled, more than one Adaptive Parameter Scheduler must be used.

When the relationship between the index variable and the tuning parameter is known to be nonlinear with a previously established shape, the Adaptive Parameter Scheduler can be used to determine a linear correction bias to adjust the fixed nonlinear parameter schedule for actual process behavior. Once the nonlinear relationship has been configured into the control logic, the correction bias is calculated by the Adaptive Parameter Scheduler and added to the output of the fixed nonlinear parameter schedule to establish the value of the scheduled tuning parameter for the controller. This feature is illustrated in **Figure 3**.

Configuration requirements and functional details of the Adaptive Parameter Scheduler are identified in **Table 4**.

Example Application

To illustrate application of the Bailey self tuning Inferential Smith Controller, a relatively simple example has been selected. This example will be used to demonstrate the unique self tuning features available with Bailey microprocessor based controllers. Brief discussions of the process, a conventional control technique, and application of the Bailey self tuning algorithm are provided.

Process Description

A process which benefits substantially from the application of self tuning control is the fired process heater shown in **Figure 4**. The product stream from one process unit must be heated to a specific temperature before it is fed into another process unit. Plant off gas, a combustible waste byproduct from the various process units within the plant, is used as the primary fuel for the heater. The objective of the control system is to precisely control the measured product temperature by regulating the flow of off gas to the heater.

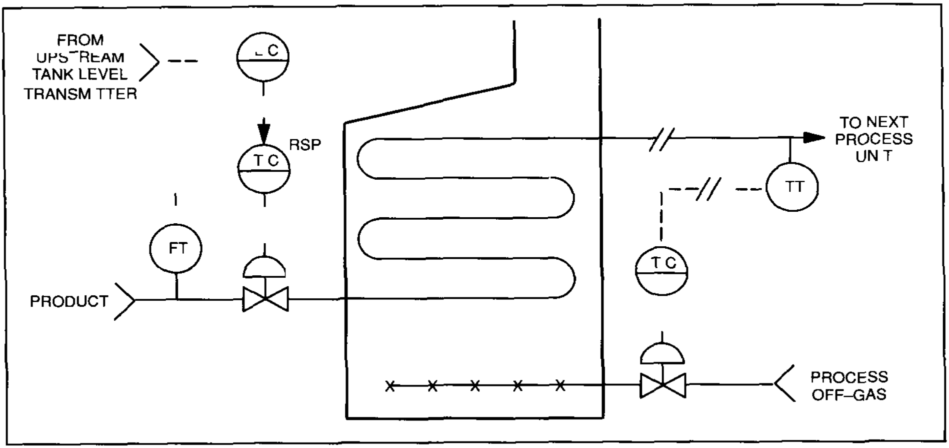

FIGURE 4   Typical Industrial Process Heater

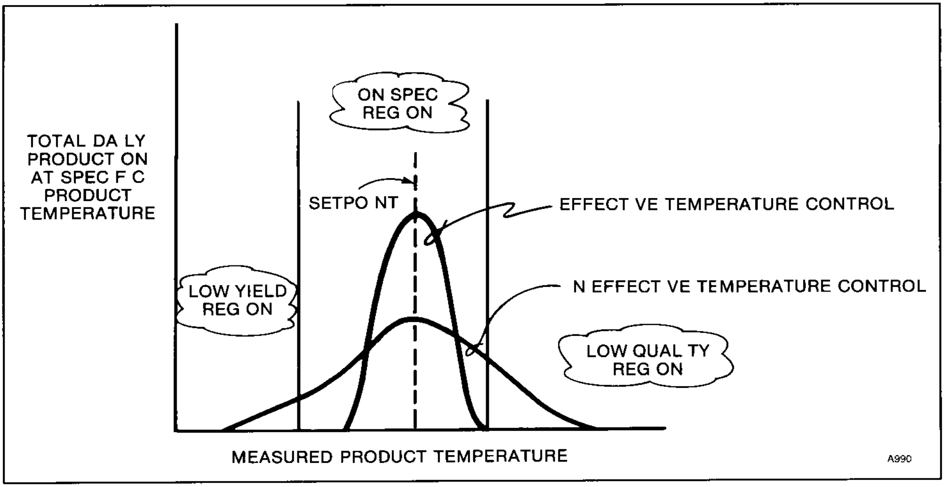

FIGURE 5 Effects of Temperature Controller Performance

As shown in **Figure 5** precise product temperature control is critical to the overall economics of the process in this example. If the temperature is too low the yield of final product will be significantly reduced increasing the average production cost for quality product. If the temperature is too high the quality of the final product is significantly reduced resulting in increased waste production and/or recycling costs which again increases the average production cost for quality product.

If the product temperature varies too much around the setpoint the cost penalties from both high and low temperature result. However if the product temperature can be effectively controlled the setpoint can be shifted to a more economically favorable value increasing the profit margin in addition to avoiding cost penalties.

Several factors complicate effective product temperature control in this example.

- **Process Deadtime** The desired product temperature is measured downstream of the heater at the inlet to the next process unit. This introduces a large transport delay or deadtime, into the heating process. When the off gas control valve position is changed it can be several minutes before the effect of this change is detected by the temperature sensor. The control action must be compensated for this deadtime or the controller will have to be detuned for control stability and the temperature will vary significantly above and below the setpoint.

- **Flow Rate Variation** The product flow through the heater changes frequently due to the control action of the upstream tank level controller. This level controller reacts to variations in plant operations and process upsets from a variety of sources. The product flow change strongly influences the dynamics of the heating process. At a higher product flow a larger change in off gas control valve position will be required to eliminate a 10°F temperature error than would be required at a lower product flow. Also this change must be made sooner and more rapidly for effective temperature control at the higher product flow. This change in product flow causes significant changes in the gain time constant and deadtime of the heating process.

To effectively stabilize product temperature with these changes in process behavior controller tuning parameters must be adjusted to accommodate the change in product flow through the heater. If the tuning parameters are not adjusted to compensate for the change in process behavior either unstable or sluggish temperature control will result as the product flow changes from the value at which the controller was tuned for optimum performance producing wide variations in product temperature.

- **Off-Gas Heating Value Variation** The heating value of the process off gas varies as a function of the process units currently operating within the plant. As the off gas heating value decreases, a larger change in off gas control valve position is required to compensate for a 10°F temperature error than would be required for off gas with a higher heating value. To effectively compensate for this change in heating process gain, controller tuning parameters must be adjusted to accommodate the change in off gas heating value. If the tuning parameters are not adjusted to compensate for the change in process gain, either unstable or sluggish temperature control will result as the off gas changes from the heating value at which the controller was tuned for optimum performance.

Conventional Product Temperature Control

The conventional approach to product temperature control for this heater utilizes a PID controller as shown in **Figure 6**. The temperature controller is tuned for effective control at a specific product flow, a specific off gas heating value and a specific product temperature setpoint. When any one of these process conditions change from the value used during initial adjustment, controller tuning will be either too fast or too slow to effectively stabilize the product temperature and major product temperature fluctuations will result.

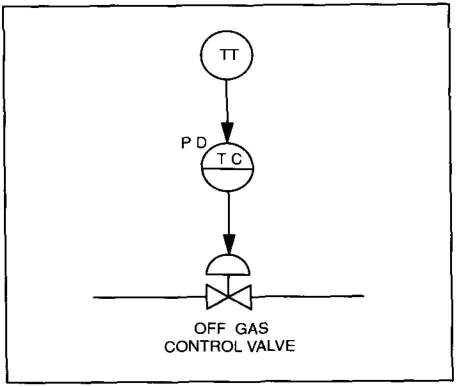

FIGURE 6 Conventional Product Temperature Control

Self-Tuning Product Temperature Control

The Bailey self tuning Inferential Smith Controller can be simply implemented on this process without any detailed engineering knowledge of the process. The self tuning ISC will effectively adjust itself for optimum control performance despite variations in process deadtime, gain and/or lag time.

However, the Bailey approach to self tuning control also has the flexibility to incorporate any engineering knowledge of the process available to minimize periods of sub optimum controller performance during self tuning. This knowledge can be effectively incorporated at the design stage, rather than during commissioning of the self tuning controller. Since there are significant economic ramifications to the performance of the product temperature controller in this example application, both basic self tuning and advanced self tuning will be discussed to illustrate the flexibility of the Bailey approach.

The basic implementation of self tuning for this example is shown schematically in **Figure 7**. Only the Model Parameter Estimator and the ISC Parameter Converter are required in addition to the Inferential Smith Controller. Aside from connecting the function blocks within the control logic, the only engineering input required is the allowable control valve movement during the automated initialization routine.

The advanced implementation of self tuning for this example is shown schematically in **Figure 8**. All detailed engineering knowledge available for the process has been utilized to optimize the effectiveness of the product temperature control. The process gain is adjusted as a function of product flow utilizing a fixed nonlinear process gain schedule from the heater manufacturer and an Adaptive Parameter Scheduler. The process lag time is also adjusted as a linear function of product flow with an adaptive Parameter Scheduler. The process deadtime is adjusted as a function of flowrate through the ISC Converter, which updates the Model Parameter Estimator and the Inferential Smith Controller.

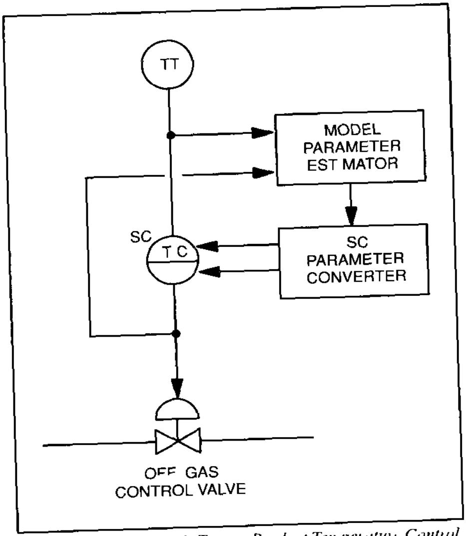

FIGURE 7 Basic Self Tuning Product Temperature Control

Advanced Self–Tuning Considerations

From the process description it is apparent that the product flow through the heater will have a major effect on the process deadtime, gain and lag time and that this flow will be changing frequently. To maintain controller performance during rapid changes in product flow, these parameters can be scheduled as a function of product flow. As the process behavior changes due to factors unrelated to product flow, the tuning parameter schedules are automatically adapted to optimize SC performance. This eliminates potentially unacceptable controller performance during the retuning period after a flow change.

Engineering analysis reveals that the process deadtime is approximately the length of time required for the heated product to travel from the heater outlet to the location of the temperature sensor. This deadtime can be approximately calculated as a function of the product flow with the following equation:

$$\text{Deadtime (sec)} = 2.45{*}D^{2}{*}L/F$$

where D is the diameter of the product pipe (inches), L is the length of pipe between the heater outlet and the temperature probe (feet) and F is the product flow (gpm). This relationship does not have to be precise. It can be approximate and still be of major benefit to controller performance.

Although the actual relationship between the process gain and the product flow is much more complex than the deadtime relationship, a linear approximation of this relationship could significantly improve controller performance without excessive information and calculations. Since the process gain is continuously re-estimated by the Model Parameter Converter and the corresponding tuning parameter is continuously recalculated by the SC Parameter Converter, the Adaptive Parameter Scheduler can be used to automatically correlate the required process gain with product flow to provide this linear approximation.

However, a more complex nonlinear relationship between the process gain and the product flow is available for this example from manufacturer heater performance tests. This relationship was established for a specific fuel and a specific product. Since this data is available, a nonlinear function will be used to schedule process gain as a function of product flowrate and the Adaptive Parameter Scheduler will be used to automatically determine the correction bias required to compensate this relationship for the actual fuel, the actual product fluid and heater performance degradation (eg. tube fouling, burner deterioration).

The process lag time will also be adjusted as a function of product flow. Although the relative merits of this automatic adjustment could be argued, it will be provided for this example because of the potential economic ramifications and the relative ease of accomplishing this function.

From the process description, the off gas heating value is also expected to vary significantly and this variation is expected to require some changes in controller tuning. Conceivably the controller gain could also be adapted as a function of an off gas heating value measurement. This would undoubtedly enhance controller performance but the cost effectiveness and the reliability of the analyzers available for this application are questionable. In this case the ISC will be allowed to self tune for changes in off gas heating value; these changes will appear as corrections in the adaptive parameter scheduler.

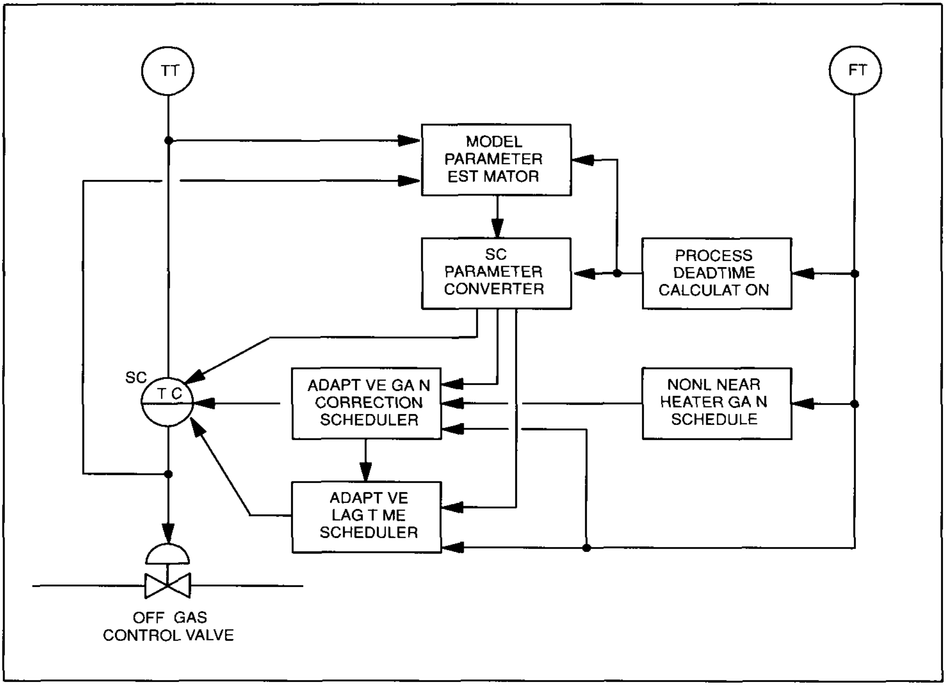

FIGURE 8 Advanced Self Tuning Product Temperature Control

Implementation

The specialized function blocks required for self tuning of the inferential Smith Controller are available in standard Bailey microprocessor based controllers (NCOM04 CLC02 and NMFC03 04 05) Any of the Bailey CRT based operator consoles can be used to initiate and monitor the automated initialization routine for the NETWORK 90 controllers A Configuration Tuning Terminal (CTT01) will be required for the LOOP COMMAND controller (CLC02)

The actual configurations required to implement the basic and advanced self tuning product temperature control in these Bailey controllers are shown in **Figure 9** and **Figure 10** Although the configurations are specifically for the discussed example they are generally applicable to a broad range of industrial process control applications requiring self tuning The configuration requirements of the standard Bailey function blocks shown are discussed in the **Bailey Function Code Application Manual**

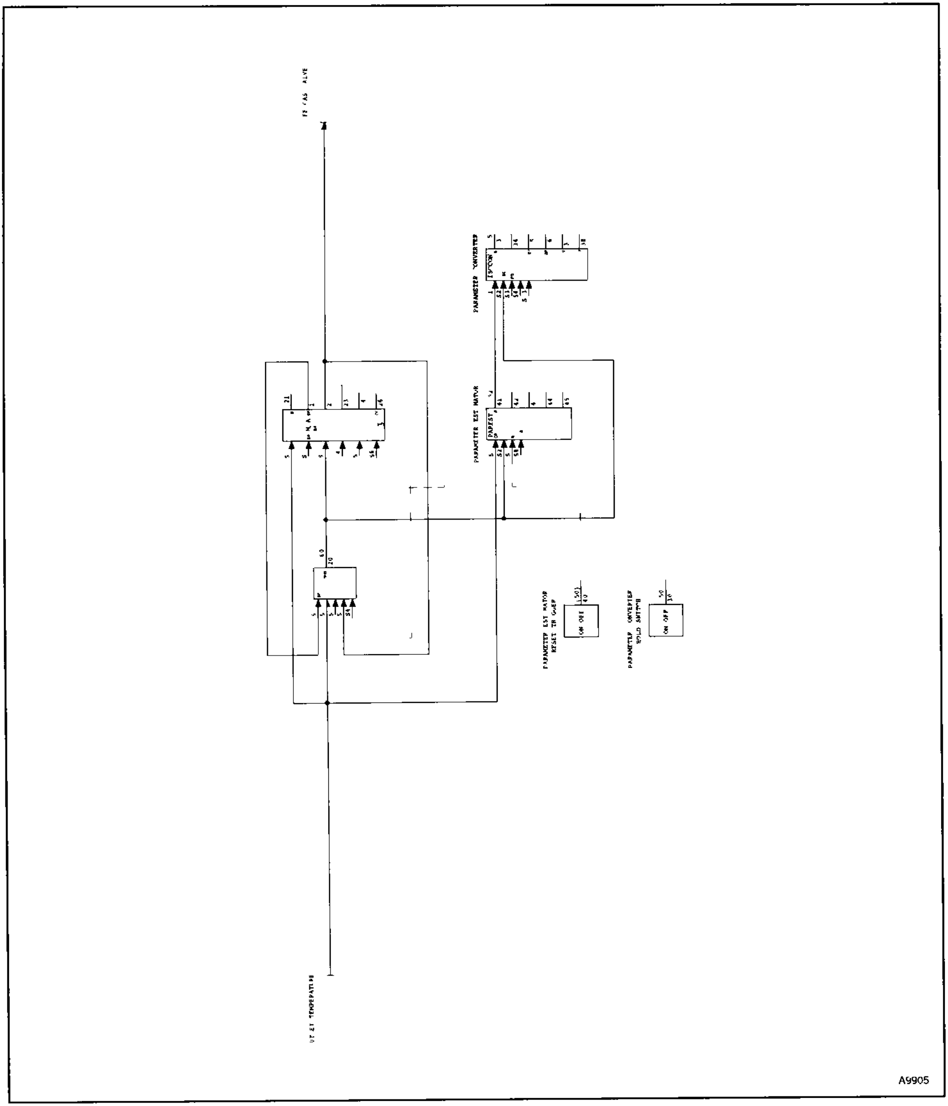

FIGURE 9 Basic Bailey Self Tuning Configuration

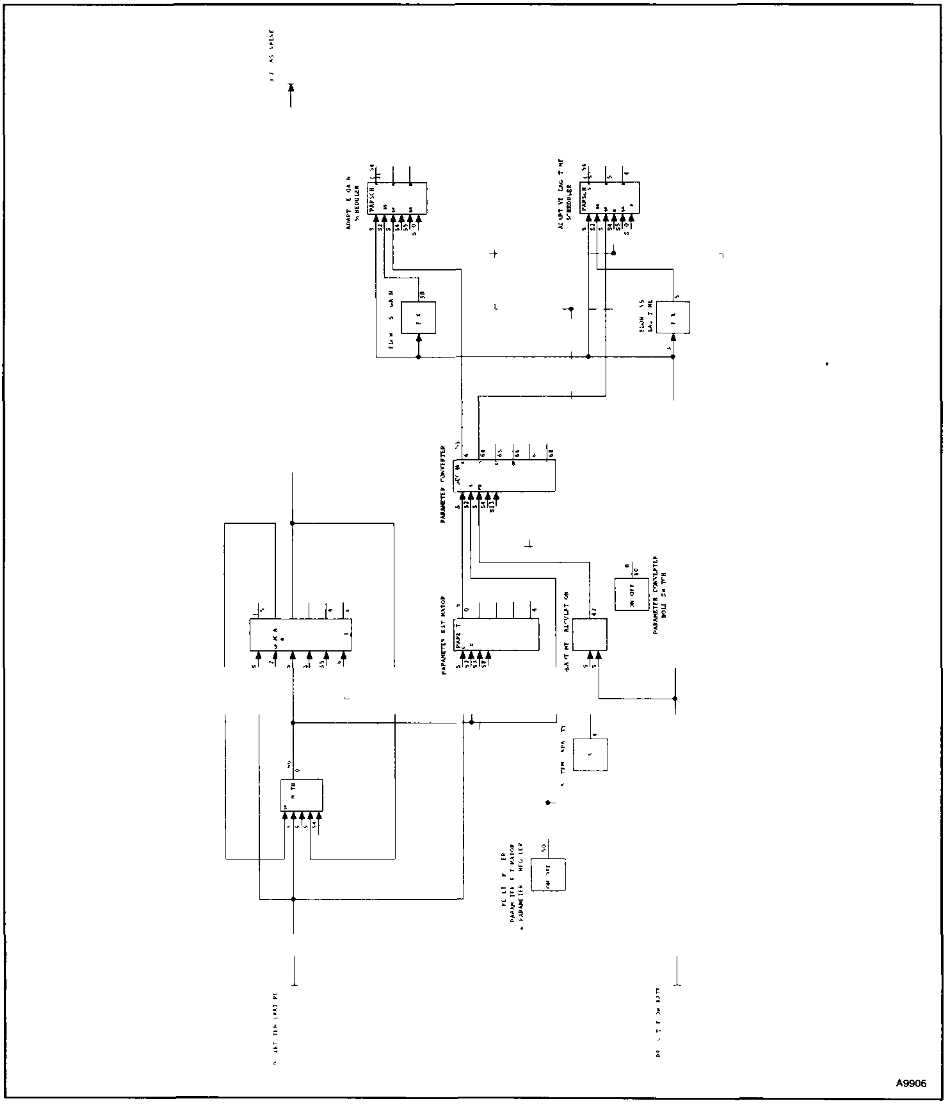

FIGURE 10 Advanced Bailey Self Tuning Configuration with Dead Time Scheduling and Adaptive Gain/Lag Scheduling

TABLE 1 Inferential Smith Controller Description

FUNCTION CODE 160 INFERENTIAL SMITH CONTROLLER

The Inferential Smith Controller (ISC) function block provides regulatory process control similar to a PID algorithm. However, the ISC has the added advantage of effective control for processes with a significant transport delay (deadtime). This algorithm functionally replaces the standard PID Controller function blocks and provides all the enhancements required for regulatory control including output limiting, tracking and external reference capabilities.

The Inferential Smith Controller utilizes a first order dynamic model with deadtime to predict the current value of the process variable based on past values of the control output. Any difference between the predicted and actual process variable is an indication of a process disturbance and a change in control output is required to compensate for this disturbance. The ISC uses the dynamic model to calculate the change in control output required. This algorithm inherently paces the control action to the ability of the process to respond.

Each specification for the Inferential Smith Controller is discussed briefly below.

Block Address of Process Variable – This specification identifies the process variable to be controlled by the ISC.

Block Address of Setpoint – This specification identifies the setpoint to which the process variable is to be controlled. This signal is typically generated from a Station function block.

Block Address of Track Reference Value – This specification identifies the track value for the ISC. The track value becomes the control output from the ISC in MANUAL mode, permitting the operator to manually control the process.

Block Address of Track Reference Flag – This specification identifies the flag which establishes the operating mode of the ISC. If the track flag is set to zero, the ISC is in MANUAL mode. If the track flag is set to one, the ISC is in AUTOMATIC mode and adjusts the control output as necessary to maintain the established setpoint.

Block Address of External Reference Value – This specification identifies the external reference value which permits the ISC to be used as the primary (outer) controller in a cascade configuration. The external reference value is the controlled process variable for the secondary (inner) controller. This signal permits the ISC to remove the dynamics of the secondary controller from its internal dynamic model of the process and prevents windup in the event that the inner controller becomes saturated.

External Reference Flag – This specification provides an external reference flag which indicates the existence of an external reference signal. When set to zero, the ISC does not monitor the external reference signal. When set to one, the reference signal is monitored and compensated for by the ISC.

Process Gain, Deadtime and Lag Time – These specifications define the dynamic process model used internally by the Inferential Smith Controller. Process gain is defined as the change in process variable divided by the change in control output and may have positive or negative sign.

Controller Time Constant – This specification establishes the desired controller response to process disturbances and setpoint changes. For tight control with an accurate model, this parameter may be set to 30% of the process lag time. For slower controller response or when the process model is not considered accurate, the value of this parameter can be increased to the process deadtime plus 300% of the process lag time.

TABLE 1 Inferential Smith Controller Description (Cont'd)

FC160 SPECIFICATIONS:

SPEC NO	TUNE	DEFAULT	TYPE	RANGE	DESCRIPTION
S1	No	5	INT	0 to *	Block Address of Process Variable
S2	No	5	INT	0 to *	Block Address of Setpoint
S3	No	5	INT	0 to *	Block Address of Track Reference Value
S4	No	0	INT	0 to *	Block Address of Track Reference Flag 0 track 1 release
S5	No	5	INT	0 to *	Block Address of External Reference Value (cascade)
S6	No	0	BOOLEAN	0 or 1	Use External Reference Flag 0 normal 1 use
S7	Yes	1 000	REAL(3)	Full	Process Gain
S8	Yes	0 000	REAL(3)	0 0 to 9 2E18	Process Deadtime (seconds)
S9	Yes	0 000	REAL(3)	0 0 to 9 2E18	Process Lag Time (seconds)
S10	Yes	9 2E18	REAL(3)	0 0 to 9 2E18	Controller Time Constant (seconds)
S11	Yes	105 000	REAL(3)	Full	Output High Limit
S12	Yes	5 000	REAL(3)	Full	Output Low Limit

* is the maximum block address permitted for the specific controller module

FC160 OUTPUTS:

BLOCK NO	TYPE	DESCRIPTION
N	REAL	Control Output

TABLE 7 Model Parameter Estimator Description

FUNCTION CODE 152 MODEL PARAMETER ESTIMATOR

The Model Parameter Estimator function block uses a *recursive least squares algorithm to identify a* mathematical model of the process. This function block calculates the parameters for a linear first order dynamic model with deadtime of the specific form

$$y_t = a \bullet y_{t-1} + b \bullet u_{t-k} + c$$

In this equation $\mathbf{y_t}$ is the value of the process variable at time **t**, $\mathbf{y_{t-1}}$ is the value of the process variable at one sample time before time **t**, $\mathbf{u_{t-k}}$ is the value of the control output one process deadtime (expressed as **k** sample time increments) before time **t**, and **a**, **b** and **c** are model parameters.

The Model Parameter Estimator continuously monitors the value of the controlled process variable and the control output. The value of the model parameters are calculated whenever the process behavior deviates significantly from the established parameters. The Model Parameter Estimator outputs the value of the calculated process model parameters, the statistical residual between the actual data and the calculated model, and the status of the parameter estimator.

The Model Parameter Estimator contains a set of heuristic rules to eliminate the practical difficulties of estimation theory. These rules prevent long term drift of the model parameter estimates during consistent process performance and inappropriate reaction of the Model Parameter Estimator to external process disturbances.

Each specification for the Parameter Estimator is discussed briefly below.

Block Address of Process Variable — This specification identifies the controlled process variable to be used by the Model Parameter Estimator.

Block Address of Control Output – This specification identifies the controller output to be used by the Model Parameter Estimator.

Block Address of Reset Trigger – This specification *identifies a reset trigger for the Model Parameter* Estimator. When this trigger changes value from zero to a one, the Model Parameter Estimator is initialized. The reset trigger also updates the Model Parameter Converter to the default settings (process gain and process lag) stored in nonvolatile memory of the SC. These settings may be updated manually by tuning the corresponding SC specifications.

Note: The estimator does not stop when the loop is in *manual or the process is shut down. Reset trigger must* be used on start up of process.

Sample Time – This specification provides time scaling for the estimation algorithm. To assure proper operation of the Model Parameter Estimator, the sample time should be selected so that it is between 20% and 50% of the process lag time. Because of the strong dependency of the calculated model coefficients on the selected sample time, when the sample time is changed more than 10% or in excess of 0.5 sec, the model coefficients are automatically initialized.

Process Deadtime – *This specification defines the* deadtime or transport delay exhibited by the process. Under–estimation of deadtime adversely affects parameter estimation more severely than over–estimation. When the Model Parameter Estimator is linked with an SC Parameter Converter, the process deadtime is automatically input by the SC Parameter Converter.

Expected Process Noise Level – The Model Parameter Estimator uses this specification in its identification of process upsets. This value indicates the maximum deviation from setpoint that can be attributed to noise in the process. The Model Parameter Estimator treats deviations greater than this value as process upsets.

TABLE 2 Model Parameter Estimator Description (Cont'd)

FC152 SPECIFICATIONS:

SPEC	TUNE	DEFAULT	TYPE	RANGE	DESCRIPTION
S1	No	5	INT(2)	0 to *	Block Address of Controlled Process Variable
S2	No	5	INT(2)	0 to *	Block Address of Control Output
S3	No	0	INT(2)	0 to *	Block Address of Reset Trigger
S4	Yes**	0.25	REAL(3)	0.25 to 9.2E18	Sample Time (sec)
S5***	Yes**	1.0	REAL(3)	0.25 to 9.2E18	Process Deadtime (sec, must be less than S4*40)
S6	Yes**	0.0	REAL(3)	0.0 to 9.2E18	Expected Noise Level of Process Variable (Peak to Peak)

* is the maximum block address permitted for the specific controller module
** automatically specified by initialization routine in ISC Parameter Converter (FC 153)
***used only when Model Parameter Estimator is not used with ISC Parameter converter (FC 153)

Caution: The relationship between S4 and S5 must be valid before the module will go into execute mode. If you are adding this block with an ISC (FC160) the sample time S4 must be greater than ISC deadtime (FC160 S8) divided by 40.

FC152 OUTPUTS:

BLOCK NO	TYPE	DESCRIPTION
N	REAL	Model Parameter a
N+1	REAL	Model Parameter b
N+2	REAL	Model Parameter c
N+3	REAL	Residual
N+4	BOOLEAN	Status of Model Parameter Estimator 0 Parameter Estimator locked on 1 New Parameter Estimation in progress

TABLE 3. ISC Parameter Converter Description

FUNCTION CODE 153 ISC PARAMETER CONVERTER

The ISC Parameter Converter function block calculates optimal tuning parameters for the associated Inferential Smith Controller using the outputs of the Model Parameter Estimator. Direct links between these function blocks simplify implementation.

The Model Parameter Estimator generates the value for the process gain and process lag time. These outputs describe process dynamics at one operating point. This information is directly converted to optimal tuning parameters for the Inferential Smith Controller at this operating point using simple algebraic equations.

The tuning parameters for the ISC (process gain and lag time) are automatically adjusted by the ISC Parameter Converter as the Model Parameter Estimator changes its estimates. However, the controller time constant for the ISC is not automatically adjusted; this time constant provides a mechanism for establishing the desired controller performance.

The ISC Parameter Converter also supervises an automated initialization routine for the self tuning Inferential Smith Controller. When the control station is set to AUTOMATIC mode after the initialization trigger is changed from zero to one, the ISC Parameter Converter exercises the control output by a series of two step changes (in opposite directions) of a size previously established (typically + 5%) and monitors the reaction of the controlled process variable to estimate the process deadtime, gain and lag time. The automated initialization routine is immediately aborted if the control station for the ISC is set to MANUAL mode. After enough data has been collected to establish statistically valid estimates, the initialization routine is automatically terminated, and the control station for the ISC is set automatically to Manual mode.

The process deadtime estimate from the initialization routine is used by the Model Parameter Estimator to determine on line values of the process gain and lag time whenever S3 specifies block address 5. If the process deadtime is externally calculated as a function of some process variable then this value is connected to S3 input and is used by the Model Parameter Estimator and ISC.

The estimated values of process deadtime, gain and lag time from the initialization routine are used by the ISC Parameter Converter to automatically establish the initial values of a number of other specifications:

- Minimum Process Gain is set to 50% of the initial process gain observed during the initialization routine.
- Maximum Process Gain is set to 200% of the initial process gain observed during the initialization routine.
- Minimum Process Lag Time is set to 50% of the initial process lag time observed during the initialization routine.
- Maximum Process Lag Time is set to 200% of the initial process lag time observed during the initialization routine.
- Controller Time Constant for the Inferential Smith Controller is set to 100% of the initial process lag time observed during the initialization routine.
- Sample Time for the Model Parameter Estimator is set to 20% of the process lag time observed during the initialization routine.
- Expected Noise Level for the Model Parameter Estimator is set based on the peak to peak value of the noise on the controlled process variable observed during the initialization routine for constant valve position.

These initialized specifications can be manually changed after the initialization routine is complete. However, they should be valid for most applications.

Upon completion or failure of the automated initialization routine, the ISC Parameter Converter automatically returns the control station for the ISC to MANUAL mode and sets the value of the appropriate controller specifications. At this point the initial settings can be monitored and validated before they are actually used by the controller. The initialization trigger must be manually set to zero for normal operation.

TABLE 3. ISC Parameter Converter Description (Cont.)

Each specification for the ISC Parameter Converter is discussed briefly below.

Block Address of Associated Model Parameter Estimator – This specification establishes the link between the ISC Parameter Converter and the associated Model Parameter Estimator. The ISC Parameter Converter obtains the estimated value of the process model parameters and the status of the estimates through this link. The process deadtime for the Model Parameter Estimator is updated through this link.

Block Address of Associated Inferential Smith Controller – This specification links the ISC Parameter Converter with the associated ISC. Updating of the ISC tuning parameters and the process deadtime occurs through this link.

Block Address for Process Deadtime – This specification locates the value of the deadtime to be used by the ISC and the Model Parameter Estimator. If the deadtime is not predicted as a function of a process variable, the default address should be used to permit the process deadtime setting of the ISC to be used by the ISC Parameter converter.

Block Address of Hold Signal – This specification identifies a hold switch for the ISC Parameter Converter. If the value of this switch is set to one, parameter conversion continues but the tuning parameters of the ISC are not automatically updated. New values for the calculated tuning parameters are available at the block outputs whenever the status of the Model Parameter Estimator indicates Parameter Estimator Locked On. When the status indicates New Parameter Estimator in Progress', the tuned ISC parameter will be displayed and the operator can manually tune the ISC. If the value of the switch is set to zero, the ISC Parameter Converter will automatically tune the parameter of the ISC specified by the adapt option. The operator can manually tune the ISC when the status from the Model Parameter Estimator indicates New Parameter Estimator in Progress.

Minimum and Maximum Tuning Parameters – These specifications are required for commissioning of the self tuning ISC and to increase the fault tolerance of ISC operation. Minimum and maximum values are preset by the automated initialization routine but can be adjusted from user knowledge of the process. In the event that the ISC Parameter Converter generates values for the tuning parameters outside of the previously specified constraints, the tuning parameters for the controller will be limited to the constrained values.

Adapt Option – This specification permits the user to select self tuning for either or both controller tuning parameters. If Adaptive Parameter Scheduler (FC154) is used, the scheduled parameter(s) should not be selected for self tuning with this specification.

Initialization Trigger – This specification provides the trigger for the automated initialization routine. When the trigger is changed from zero to one and the ISC is in manual mode, the initialization routine is activated. As a safeguard, the station associated with the ISC must then be placed in AUTOMATIC mode for initialization to proceed. The routine is automatically terminated when adequate data has been generated for process identification. As long as the initialization trigger equals one, the process deadtime will be that estimated by the initialization routine. This value can be changed manually by tuning the ISC. The Model Parameter Estimator is automatically updated to this value. When the initialization trigger is set equal to zero, Specification S3 (Block Address for Process Deadtime) is utilized.

Maximum Control Output Change for Initialization – This specification establishes the maximum change from the manually set valve position to be permitted during the automated initialization routine. One can specify either a positive or negative step change.

TABLE 3 ISC Parameter Converter Description (Cont'd)

FC153 SPECIFICATIONS:

SPEC NO	TUNE	DEFAULT	TYPE	RANGE	DESCRIPTION
S1	No	5	INT(2)	0 to *	Block Address of Associated Model Parameter Estimator
S2	No	5	INT(2)	0 to *	Block Address of Associated ISC
S3	No	5	INT(2)	0 to *	Block Address for Process Deadtime
S4	No	0	INT(2)	0 to *	Block Address of Hold Signal
S5	Yes**	9.2E18	REAL(3)	Full	Minimum Allowable Value for Process Gain
S6	Yes**	9.2E18	REAL(3)	Full	Maximum Allowable Value for Process Gain
S7	Yes**	0.0	REAL(3)	0.0 to 9.2E18	Minimum Allowable Value for Process Lag Time
S8	Yes**	9.2E18	REAL(3)	0.0 to 9.2E18	Maximum Allowable Value for Process Lag Time
S9	No	0	INT(2)	0 to 3	Adapt Option 0 no adapt 1 adapt process gain only 2 adapt lag time only 3 adapt both process gain and lag time
S1	Yes	0	INT(1)	0 to 1	Initialization Trigger
S11	Yes	5.0	REAL(3)	Full	Maximum Control Output Change for Initialization

* is the maximum block address permitted for the specific controller module
** automatically specified by the initialization routine

FC153 OUTPUTS:

BLOCK NO	TYPE	DESCRIPTION
N	REAL	Estimated Process Gain
N+1	REAL	Estimated Process Time Constant
N+2	REAL	Adjusted Process Deadtime
N+3	REAL	Estimated Process Operating Point
N+4	REAL	Initialization Status 0 normal operation 1 initialization failed or aborted 2 initialization in progress
N+5	BOOLEAN	Pulse output from 0 to 1 and back to 0 after 5 cycles, initiated after completion of the automated initialization routine

TABLE 4 Adaptive Parameter Scheduler Description

FUNCTION CODE 154 ADAPTIVE PARAMETER SCHEDULER

The Adaptive Parameter Scheduler function block allows knowledge of process characteristics to be used to adjust the tuning parameters for the associated Inferential Smith Controller function block This feature optimizes controller performance for predictable changes in process operation and prevents periods of potentially unacceptable control while the ISC is retuning itself to these changes

The Adaptive Parameter Scheduler can be used to automatically establish the relationship between an ISC tuning parameter and a measured or calculated index variable using linear regression The Adaptive Parameter Scheduler uses this relationship to automatically adjust the specified ISC tuning parameter based on the value of the specified index variable

Alternatively the Adaptive Parameter Scheduler can be used to automatically determine the correction bias required for a pre established gain schedule This permits a non linear relationship to be established between the ISC tuning parameter and the index variable with automatic correction of the relationship for design inaccuracies and/or changes in process behavior

The Adaptive Parameter Scheduler utilizes a binned data structure for regression of the linear relationship between the index variable and the correction bias The range of the index value is automatically divided into ten bins and when a valid data set becomes available it is stored in the bin corresponding to the value of the index variable for the data set Only one data point is stored in each bin As new data becomes available for a bin the old data is replaced and the regression is recalculated To facilitate commissioning of the Adaptive Parameter Scheduler when there is only one data set a line passing through the data point with zero slope is assumed

EQUATIONS:

Output Output from Fixed Gain Schedule (at S2) + Correction Bias (at block address N)

Correction Bias $Ax + B$,

where **x** is the value of the index variable (at S1)

The A and B coefficients are updated by the regression algorithm

Each of the specifications for the Adaptive Parameter Scheduler is discussed briefly below

Block Address of Index Variable This specification identifies the index variable used by the Adaptive Parameter Scheduler

Block Address of Fixed Gain Schedule This specification identifies the output of the associated fixed gain schedule If no pre established gain schedule is to be used this specification should be set to block address 5 (default value) which has a constant value of zero

Block Address of Scheduled Parameter This specification identifies the estimated value of the tuning parameter to be scheduled This value is used to determine the relationship between the tuning parameter and index variable

Block Address of Reset Trigger This specification identifies an external trigger used to reset the regression data When this trigger changes from zero to one all historic data used for determining the correlation equation is erased and the correction bias is set to zero

Address of Block Containing Parameter to be Adapted – This specification identifies the block address for the parameter to be adjusted by the Adaptive Parameter Scheduler

Specification to be Adapted This specification identifies the exact specification at the identified block address which is to be adjusted by the Adaptive Parameter Scheduler

Minimum and Maximum Values for the Index Variable – These specifications define the allowable range for the index variable They also define the data bin structure used for regression

Block Address of Coefficient Update Flag – This specification allows the user (as an option) to suspend the recalculation of the A & B coefficients The correction bias will still be computed and the output updated Also the parameter in the target block and specification continues to be updated

TABLE 4 Adaptive Parameter Scheduler Description (Cont'd)

FC154 SPECIFICATIONS:

SPEC NO.	TUNE	DEFAULT	TYPE	RANGE	DESCRIPTION
S1	No	5	INT(2)	0 to *	Block Address of Index Variable
S2	No	5	INT(2)	0 to *	Block Address of Fixed Gain Schedule
S3	No	5	INT(2)	0 to *	Block Address of Scheduled Parameter
S4	No	0	INT(2)	0 to *	Block Address of Reset Trigger
S5	No	5	INT(2)	0 to *	Block Address of Spec to be Adapted
S6	No	0	INT(1)	0 to 255	Spec to be Adapted
S7	No	0 0	REAL(3)	Full	Minimum Index Value
S8	No	0 0	REAL(3)	Full	Maximum Index Value
S9	No	0 0	REAL(3)	Full	Spare Real Parameter
S10	No	0	INT(2)	0 to *	Block address of Coefficient Update Flag 1 Hold Update of A and B 0 Update A and B

* Is the maximum block address permitted for the specific controller

FC154 OUTPUTS

BLOCK NO	TYPE	DESCRIPTION
N	REAL	Scheduled Tuning Parameter
N+1	REAL	Coefficient A of Correction Equation
N+2	REAL	Coefficient B of Correction Equation

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