Adaptive Predictive Expert Control

ADEX Configurator
User Manual

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Contents

About This Manual

This manual describes the tool that enables the user to configure ADEX Controllers and the ADEX Configurator, both of which are used in all ADEX systems. This manual also presents the methodology for the configuration of the structural variables which determine the dynamic behaviour of the controllers.

Organization of This Manual

This manual is divided into two parts:

Part I - Configuration of ADEX Controllers - This section explains the ADEX Configurator and the necessary concepts for the configuration of ADEX Controllers.

Part II - Choice of Structure Variables - This section explains how to choose the most important structural variables in an ADEX Controller.

Conventions Used in This Manual

This icon denotes a note, which alerts you to important information.

This icon denotes a warning, which should not be overlooked if the system is to continue to function correctly.

Related Documentation

The following documents contain information you might find helpful as you read this manual:

- *ADEX Methodology*

Part I

Configuration of ADEX Controllers

Basic Concepts

It should be remembered that the structure of the multivariable controllers MIMO can be understood as a group of MISO controllers containing the same number of controllers as variables in the process to be controlled. Hence, in the configuration process, there is always a MISO controller selected for configuration within the ADEX controller. An ADEX controller with one PV only, one OUT only and with either one or more or no PERTS, is a particular case within this general formulation. ADEX COP assumes:

- That the user will first configure an AP domain for each of the MISO controllers which will be called AP-C ('C' for 'Central domain' i.e. between upper and lower domains). The limits of these domains will, by default, be those of the corresponding ranges of the PV.

- The user will be able subsequently to configure 1 or 2 AP additional domains for each MISO controller, called AP-U (Upper) and AP-L (Lower) taking into account that establishing the limits should correspond to those of AP-C. For this purpose, the user will change to the Configuration Domain to set the relevant limits for that domain.

- The domains defined will always cover the corresponding ranges of the PV.

- Once the desired domains are configured, the user can continue to configure the Expert Domains. For each of the MISO controllers, an EX-U (Upper) domain can be defined with a range above the PV and conversely, an EX-L (Lower) domain can be defined with a range below the PV.

- Once the controller configuration is complete, the user can change the status of the controller to 'Ready", but it is always possible to return to configuration mode to make changes or even delete a domain.

Elements in the Configuration Window

In order to change the default values of each controller configuration, double click on the name of the controller. The configuration screen will be displayed as shown in Figure 1. All the parameters will have default values.

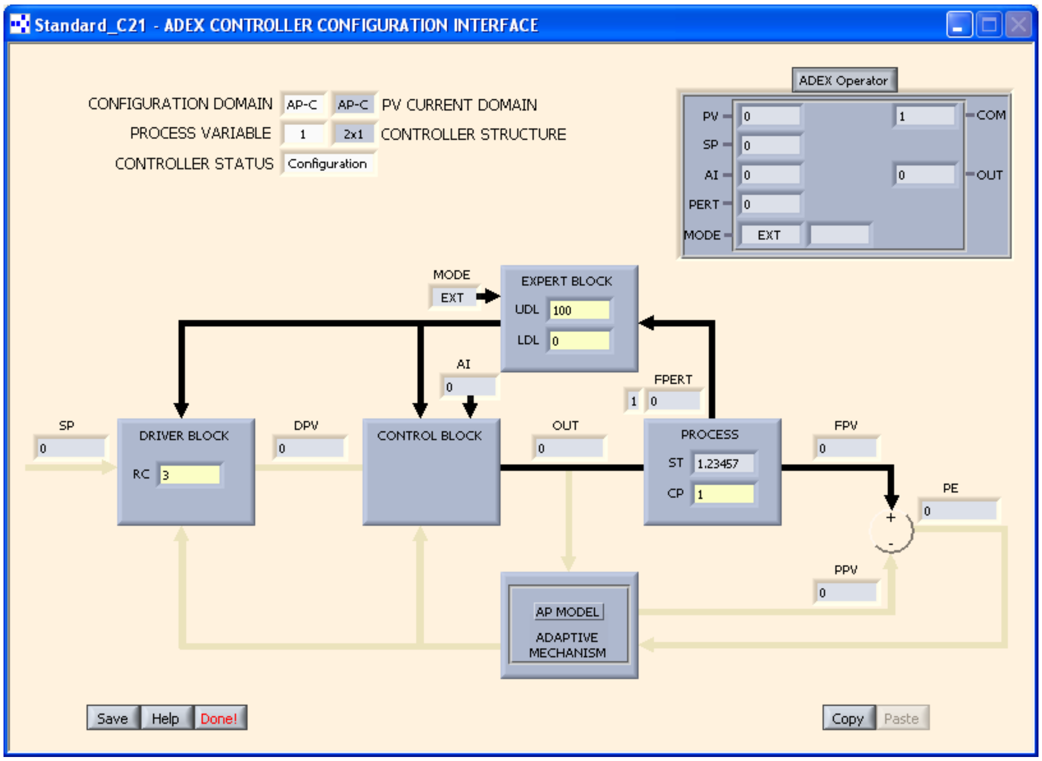


FIGURE 1 - CONFIGURATION WINDOW OF THE ADEX CONTROLLERS

Note that any of the MISO controllers selected is by default PV1 and referred to as “PROCESS VARIABLE 1”, as shown in Figure 1, since it is a single controller.

- The top left hand corner shows the “CONFIGURATION DOMAIN” and the “PV CURRENT DOMAIN” for the selected MISO controller. The configuration domain box enables the user to select any of the other domains (shown in the list when the box is clicked) for configuration.

- The ADEX controller blocks are as follows: **PROCESS**, **EXPERT BLOCK**, **DRIVER BLOCK**, **CONTROL BLOCK** and the **AP MODEL ADAPTIVE MECHANISM**. The first three of these blocks display the parameters of the selected MISO controller which are configurable by the user.

- **PROCESS**: Two defaults values are presented
  - **ST** - Sample Time
  - **CP** - Control Period for the AP-C domain as shown in Figure 1.

These parameters are common to all the MISO controllers and the ADEX controller will always use the values set for PV1 (MISO 1).

- **EXPERT BLOCK:** Two default values are presented
  - **UDL** - Upper limit of the expert domain.
  - **LDL** - Lower limit of the expert domain.

- **DRIVER BLOCK:** One default value is presented
  - **RC** - Rate of Change. This is the maximum rate at which the variable should change in time.

When the EXPERT BLOCK, DRIVER BLOCK, CONTROL BLOCK and the AP MODEL ADAPTIVE MECHANISM are double clicked, configuration windows are displayed for each one. As is explained in the following sections, the user can determine the desired function for each of the blocks by replacing the default values. As can be seen, the ADEX blocks are represented by option tabs which are permanently active when they are relevant to the domain of the selected configuration or otherwise, they remain inactive and are dimmed.

- The principal real time variables of each MISO controller are shown in smaller windows in Figure 18 and are outlined below:

1. The MODE variable, which together with the variable PV of the current domain, determines basically the type of operation of the Expert Block for the corresponding MISO system.

2. The MODE variable, which together with the variable PV of the current domain, determines basically the type of operation of the Expert Block for the corresponding MISO system.

3. The set-point (SP) which is input to the Driver Block and the desired process variable (DPV) which is output from the Driver Block and input to the Control Block.

4. The output from the Control Block (OUT) to be applied to the Process, the perturbation which acts on the process (FPERT) and the Filtered Process Variable (FPV) output from the process.

5. The Predicted Process Variable (PPV) which is output from the AP MODEL and,

6. the Prediction Error (PE) are both shown when the operation is functional.

- The lines showing the interrelationships between the ADEX blocks. These lines appear black when the interrelation is active between the blocks for the selected MISO system. Otherwise they are dimmed. As shown in Figure 1, the MODE variable is EXT or “External”. Only the lines in the upper part of the screen are shown in black and therefore active. In this case, the Expert Block determines that the Driver Block and the AP Model adaptive mechanism remain inactive. It also has determined the functioning of the Control Block which produces an OUT equal to the AI.

- There is an option ADEX Operator shown in Figure 1 which when double clicked, displays an Operator scheme, showing the values of the Operator I/O variables of the ADEX controller in real time, in relation to the selected MISO controller. This window is shown in the top right hand of Figure 1.

- Control option tabs,

  1. **[Save]** Save the configuration of the Controller
  2. **[Help]** Open the Help screen for controller configuration.
  3. **[Done]** Return to the window with the controller list after saving the controller configuration.

Controller Status

In order to monitor the status of each controller once ready for operation, and to show if there are any execution errors, a configuration window is displayed with an indicator called “CONTROLLER STATUS”. (see Figure 18). The user can change the status of the controller by changing this value. The next section explains the four possible values:

- **Configuration** - Under this status, the internal functions of the controller are being defined/ configured and so it is not available for operation. This is the initial status assigned as soon as the controller is created.

- **Ready** - This status indicates that the controller is already configured and ready for operation. This status can be set by the user by clicking on the box beside "Controller Status" (shown in the top left corner of Figure 18) whenever the controller configuration process is complete.

- **Operation** - Indicates that the controller is functioning as part of he control and optimization scheme. This status is assigned automatically by ADEX COP when the COS is in operation and in communication with the local area network.

- **Connecting** - This status is transitory and assigned automatically by ADEX COP when communication between the controller or the COS and the local area network has been lost.

Configuration of the AP Domains

Process

The parameters which are configured within the Process Block are common to all the MISO controllers and are established in the configuration of the MISO controller for PV1 which determines its value for the whole of the ADEX controller as explained in the following:

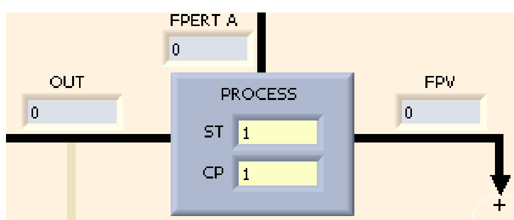


FIGURE 2 - PROCESS BLOCK

- **ST** - *Sample Time*, which determines the frequency with which the ADEX controller receives information, particularly the current values of the PV measurements from the output vector of the process, the perturbation signal 'PERT', the input vector 'AI' and the vector of operating mode 'MODE'. The sample period is the execution time period of the logic schemes which execute the **PROCESSOR** cycle time, and its value is displayed in seconds in this field.

- **CP** - *Control Period,* determines the number of sample periods between two control actions generated by the ADEX controller when under automatic control. The value can be established through the keyboard or via the logic of the control scheme. The procedure is as follows:

    1. If the user types in a positive number, the period of control is defined in terms of sample periods.

    2. If the user types in a zero, the control period will be determined by the logic scheme and transferred via the corresponding operator 'pin' in the logic scheme.

    3. If the user types in a negative number, the control instant will occur when the ADEX controller detects a change in the signal sent via the operator pin mentioned above. A control instant will take place if it is detected that there has not been a change following the set number of sampling periods since the last control instant.

In general, it would be convenient to use shorter sampling periods in order to receive as much information as possible about the process. This information can be used to obtain a convenient filtered process variable (FPV) from the process variable vector. In a SISO process, the selection of the control period must take into account the response time of the process, for example, approximately 95% of the time it takes for a process variable (PV) to stabilize after the application of a step change in control signal (OUT). A reasonable value for the control period various normally between 1/10 and 1/40 of the response time. In this case, since the process response time may be different for different MISO controllers, the choice of a common control period needs to be a compromise between both response times.

Control Block

When the user clicks on the Control Block tab shown in Figure 1, the parameter configuration window shown in Figure 3 appears.

On the left hand side, the window shows a column of variables which form part of the Control Block for the selected MISO controller. In this case, the variables, from top to bottom, are PV, OUT and PERT where PV and OUT are the corresponding variables of the process and output of the controller MISO, and PERT is an input variable which has an influence on the evolution of the process variable. Each one of these variables has associated parameters which can be configured by the user in this window.

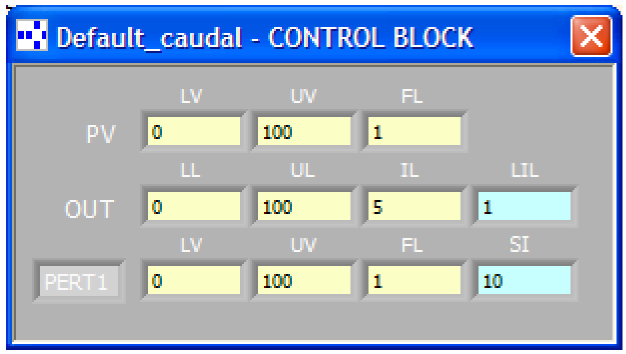


FIGURE 3 - PARAMETERS DEFINED IN THE CONTROL BLOCK

The parameters related to the variable PV of the process are:

- **LV** - Lower value, which is the bottom of the range of values measurable by the process.
- **UV** - Upper Value, which is the top of the range of values.
- **FL** - Filtered constant. The filtered value of the process variable at the sampling instant k FPV(k) is obtained by measuring the value PV(k), using FL as follows:

$$FPV(k) = FL * PV(k) + (1-FL) * FPV(k-1) \quad (1)$$

If PV(k) is contaminated with measurement noise, the use of this first order filter (1) produces a better estimate of the process variable FPV(k).

The parameters related to the output OUT of the controller MISO are.

Los parámetros relacionados con la salida OUT del controlador MISO son:

- **LL** - Lower limit for the controller output.
- **UL** - Upper limit for the controller output.
- **IL** - Incremental limit for the controller output.

- **LIL** - Lower incremental limit for the controller output. This reduced control limit is applied when the process is in steady state close to the set point.

It is important to note that the user must pay special attention to define a variation range for the actual range of the controller when introducing these limits, that is, a range of variation in which any change in the value of OUTn has a particular and unique effect on the process variable PVn of the process.

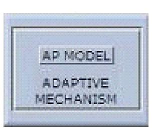
The parameters related to the perturbations are the same as those related to PV except the LIL which does not exist and therefore is substituted by:

- **SI** - Significant increment. This is the absolute value of the increment in PERT which if it occurs, relieves the controller of the limit LIL, although the PV continues close to the SP. This allows the controller to respond with a greater control action and thereby reduce the impact that PERT would otherwise have on PV.

If the MISO controller corresponding to the other PV is selected and the Control Block button clicked, the same window will appear, but this time with the values of this MISO controller.

Warning! It is important for the user to make an appropriate selection of SI for OUT2 in such a way that, under this absolute value, the incremental changes to OUT2 can always be compensated by incremental changes in OUT1, under the value of LIL.

Adaptive Mechanism



When the user clicks on the Adaptive Mechanism button shown in Figure 1, the parameter configuration window shown in Figure 4 appears, if the MISO controller selected corresponds to that of PV1. The detailed information relating to the variables, whose names are shown to the far left, is displayed in each line of parameters and these variables can be selected by means of a pop-up menu as shown in Figure 4.

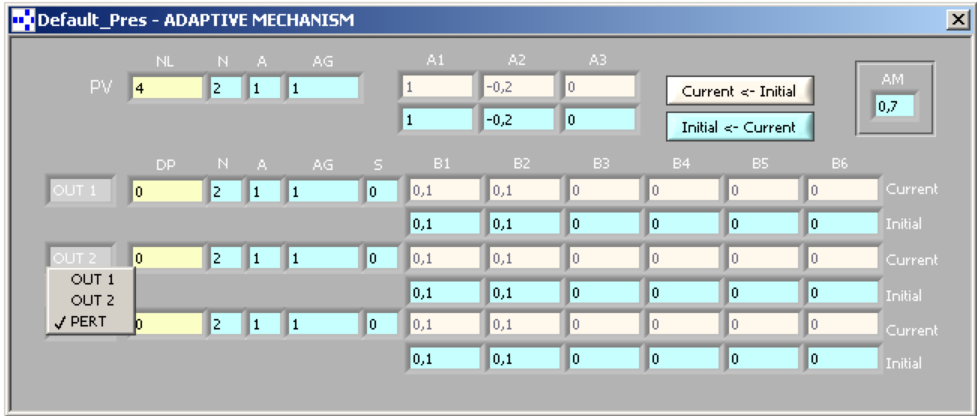


FIGURE 4 - ADAPTIVE MECHANISM PARAMETERS

These variables are considered by the Adaptive Predictive model and are used by the MISO controller in the adaptive mechanism defined as follows:

$$PV1(k|k\text{-}1) = A1(k\text{-}1) * PV1(k\text{-}1) + A2(k\text{-}1) * PV1(k\text{-}2) + \ldots \quad (2)$$
$$\ldots + B1(k\text{-}1) * OUT1(k\text{-}1\text{-}DP) + B2(k\text{-}1) * OUT1(k\text{-}2\text{-}DP) + \ldots$$
$$\ldots + C1(k\text{-}1) * OUT2(k\text{-}1\text{-}DPC) + C2(k\text{-}1) * OUT2(k\text{-}2\text{-}DPC) + \ldots$$
$$\ldots + D1(k\text{-}1) * PERT(k\text{-}1\text{-}DPD) + D2(k\text{-}1) * PERT(k\text{-}2\text{-}DPD) + \ldots$$

PV1(k|k-1) represents the estimated value of PV1 in the control instant k, obtained from the previous available instant k-1. As a consequence, this estimated PV1 is obtained from the value of the adaptive predictive model parameters (AP) Ai, Bi, Ci, and Di and the measured values of PV1, OUT1, OUT2 and PERT at the k-1 instant and at the previous instants. DP, DPC and DPD are integers which represent the delay in control periods in which a change in OUT1, OUT2 and PERT respectively produce a change in the value of PV1.

The estimated PV1(k|k-1) above can differ from PV1(k), the measured value of PV1 at instant k, with an estimation error of ε(k) as given by

$$\varepsilon(k) = PV1(k) - PV1(k|k\text{-}1) \quad (3)$$

The values of the parameters Ai, Bi, Ci and Di at instant k-1 are changed at the instant k by the adaptive mechanism using functions of the form:

$$Ai(k) = Ai(k\text{-}1) + \text{a function of } \varepsilon(k)$$
$$Bi(k) = Bi(k\text{-}1) + \text{a function of } \varepsilon(k)$$
$$Ci(k) = Ci(k\text{-}1) + \text{a function of } \varepsilon(k)$$
$$Di(k) = Di(k\text{-}1) + \text{a function of } \varepsilon(k) \quad (4)$$

These functions are defined in such a way that ε(k) tends rapidly to zero. This adaptation only happens when a statistical criteria indicates the ε(k) is due to a error in the model (lack of precision in Ai and Bi) and not caused by noise in the measurements or unknown perturbations. For more details see references [5].

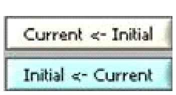
The parameters related to the process variable PV1, shown in the window displayed in Figure 21 are as follows:

- **NL** - Noise Level indicating the maximum variations which can be found in the measurement of PV1 while OUT1, OUT2 and PERT are constants and the process is in a steady state. These variations can be caused by measurement noise which occurs in the PV and also by the dynamic effect of other variables not taken into account in the AP model.

- **N** - Appears in the row of parameters associated with the PV and also in the row of a parameters associated with OUT. In the first case it is the number of parameters Ai taken into consideration in the AP model while in the second, it is the number of Bi parameters. The remainder of the AP model parameters shown, but not considered, are effectively ignored and treated as though their values were zero.

- **A -** This parameter is also presented in the rows of PV and OUT parameters. The value can be 0 – disabled or 1 – enabled, and refers to the enabling of the adaptation mechanism for the Ai and Bi parameters respectively.

- **AG** - Adaptation Gain. As in the case of N and A, this parameter appears in the PV1 and the OUT1 rows. Sometimes, it is possible to improve the function of the adaptive mechanism by changing the internal range of the variation of some I/O variables in the AP model simply for reasons of adaptation. The internal range of variation is defined by default as a percentage above the range of variation in the variable defined in engineering units. The parameter AG will change the internal range of variation in PVI or OUT1, multiplying the default by AG to obtain the adjusted range value.



- **A1, A2, A3 Actuales** - The values of these parameters represents the current value of adaptation generated by the adaptive mechanism for the corresponding Ai parameters of the AP model. The user cannot change them unless the button **[Current ← Initial]** is clicked to revert the current A1, A2, and A3 parameter settings to their initial values.

- **A1, A2, A3 Iniciales** - The values of these parameters are those introduced at the very beginning by the user to initialize the AP model prior to putting the adaptive mechanism into action. The user can replace the initial values at any time, by replacing them with the current values clicking on **[Initial ← Current].**

The parameters related to the output OUT1 of the selected MISO controller shown in Figure 4 are as follows:

- **DP** - Delay Periods. A change in OUT1 will require a certain number of control periods before a change will start to develop in PV1. This number of control periods minus 1 is what is termed a delay period.

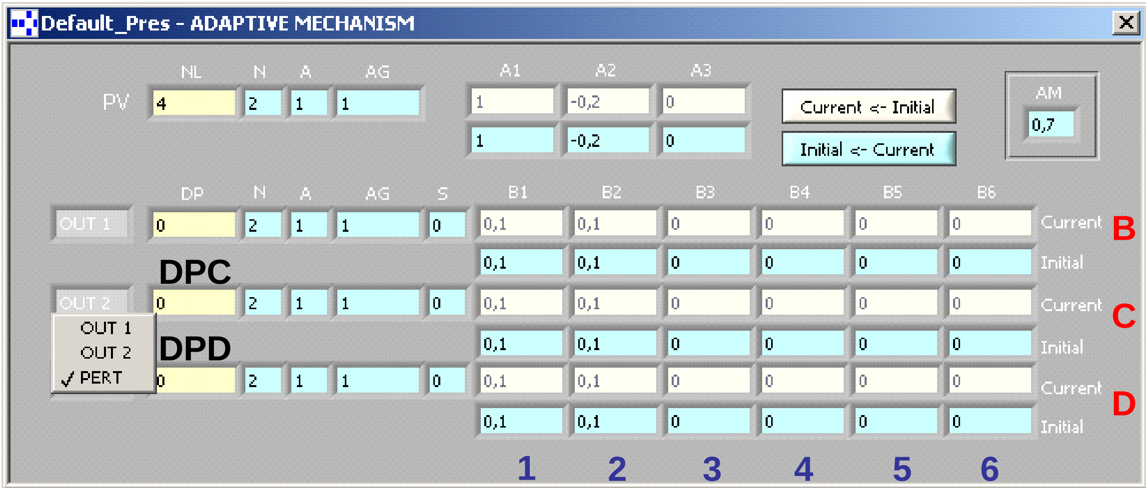
- **N, A, AG** - The values of these parameters are important for OUT1 and related to the parameters Bi in the AP model, equivalent to what has already been described for PV1.

- **S -** Sign (+/-) of the static gain of the process which will be made equal to 1 if the response of PV1 is positive and if an increment in the output from the controller OUT1 is also positive. Otherwise, the S will be made equal to -1. The value of S is used internally to diagnose an undesirable result in the 'current' functioning of the Adaptive Mechanism. When the current values of AP model parameters are working satisfactorily, the derived static gain will be positive. To ensure this, the value of S is used as a multiplier for the Bi parameters. When the derived static gain is negative, the parameters inside the AP model may be re-initialized. The user can disable this internal test by setting the value of S to 0.

- **B1 a B6 Actuales** - The values of these parameters represent the current value of the adaptation generated by the adaptive mechanism for the corresponding parameters Bi of the AP model. The user cannot change this unless the button **[Current ← Initial]** is clicked to reset the current values back to initial (B1 to B6).

- **B1 a B6 Iniciales** - The values of these parameters are introduced by the user to provide initial values for the Bi parameters of the AP model before the adaptive mechanism comes into action. The user can replace them at any time by clicking on the **[Initial ← Current]** button**.**

In Figure 4, shown below again for clarity, all the parameters of the AP model are displayed.



PV1(k|k-1) = A1(k-1) *·PV1(k-1) + A2(k-1) * PV1(k-2) + … (2)
…+ B1(k-1) * OUT1(k-1-DP) + B2(k-1) * OUT1(k-2-DP) + …
…+ C1(k-1) * OUT2(k-1-DPC) + C2(k-1) * OUT2(k-2-DPC) + …
…+ D1(k-1) * PERT(k-1-DPD) + D2(k-1) * PERT(k-2-DPD) + …

These parameters correspond to the rows of the AP model shown above. Row B refers to the parameters related to OUT1, row C to those of OUT2 and row D to those of PERT. The row letters are added for illustration.

The columns are effectively numbered 1-6 (shown here for illustration) which means, for example, that parameter C5 is displayed in column 5 of OUT2 and parameter D1 is displayed in column 1 of PERT. The delays (DP) are effectively DPC for OUT2 and DPD for PERT.

The row B delay period is referred to simply as DP.

- **AM** - Adaptive Mechanism. This parameter adjusts the speed of adaptation of the AP model between 0 (no adaptation takes place) to 1 (maximum speed of adaptation) with intermediate speeds between.

Finally, it is important to note that if the MISO controller corresponding to PV2 is selected, the window shown in Figure 21 will appear the same but with all the parameters corresponding to PV2.

Expert Block

The variables displayed in the Expert Block are shown in Figure 5 and are as follows:

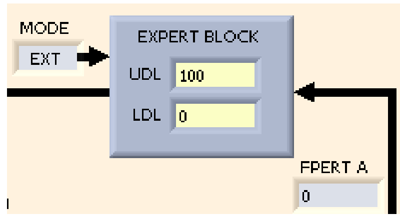


FIGURE 5 - EXPERT BLOCK

- **UDL** - Upper Domain Limit. This defines the value of the upper limit of the process variable. The system uses limits to define appropriate responses to the value of the process variable PV in terms of a corresponding OUT.

- **LDL** - Lower Domain Limit. This defines the value of the lower limit of the process variable. Both the lower and upper limits will be wider (if an Expert Domain is defined) or equal (if there is no Expert Domain defined) to the limits set for the AP domains.

If the Expert Block is clicked, a small window as shown in Figure 6 will appear.

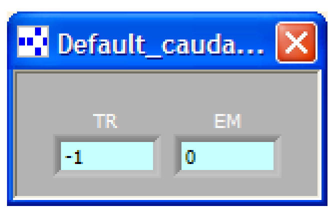


FIGURE 6 - EXPERT BLOCK PARAMETERS

This Expert Block window enables the user to configure the following parameters:

- **TR** - Time of Residence. The value introduced in this box determines the number of control periods which the AP model needs to acquire the minimum data (I/O values) sufficient to allow the calculation of a control signal. The default value is -1 and in this case, the system itself calculates the minimum number of control periods necessary to fill out all the variables of the AP model with significant data before carrying out the calculations. If the value assigned to TR is less than the minimum number, the AP model will start to carry out calculations assuming that previous variable values of the AP model are the same as the most recent ones where there is no information available.

- **EM** - Entry Mode. The value of this parameter determines which values will be taken by the current parameters of the AP model when the output value of the selected MISO process passes from a particular domain to the selected AP configuration domain. There are 4 different options which correspond to the following EM values:

  0 – Leaving the value at zero (default value), the Expert Block reinitializes the current parameters of the AP model in accordance with the initial values assigned for the selected domain.

  1 – The Expert block will reinitialize the values of the current AP model parameters in accordance with the latest current values of the selected domain.

  2 – If the PV comes from an AP domain, the current parameters of the AP model maintain the latest current values from that domain. If the PV comes from an Expert Domain, the values of the current parameters reset themselves to their initial values automatically.

  3 – If the PV comes from an AP domain, the current parameters maintain the latest current values obtained in that AP domain in the same way as described in point 2. If the PV comes from an Expert Domain, the values of the parameters also maintain the latest values in the selected domain.

Driver Block

The Driver Block has a small box inside labeled “RC”:

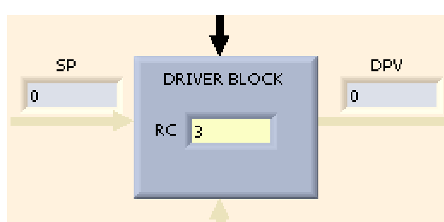


FIGURE 7 – DRIVER BLOCK

- **RC** - Rate of Change. This parameter limits the rate of change of the trajectory which drives the process output towards the set point. The value of the RC is introduced in the form of engineering units per control period. The rate of change can be established internally or externally via the control scheme logic. The procedure is the following:

    a) If the user establishes a positive increment in the engineering units using this tab, this increment will determine the rate of change in the functioning of the corresponding MISO controller.

    b) If the user inserts 0 inside this box, the rate of change will be determined by the logic executed in the **PROCESSOR** (COL) and be transferred via the pin corresponding to the operator.

If the Driver Block tab is clicked, a small window as shown in Figure 8 will appear:

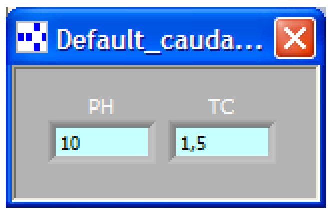


FIGURE 8 - PARAMETERS OF THE DRIVER BLOCK

This window of the driver block enables the user to set the following parameters:

- **PH** - Prediction Horizon. This parameter defines the number of future steps (control periods), starting from the current control instant and projected along the desired output trajectory of the process. The corresponding process control signal for the OUT of the selected MISO system is calculated in such a way that the predicted variable is equal to the desired variable at the end of the prediction horizon.

- **TC** - Time Constant. This parameter determines the time constant, in control periods, of the default desired trajectory generated by the driver block from a second order model with a static gain and damping factor of 1. For example, if the TC is equal to 1.5 control periods, the desired process output will be delayed nearly 9 control periods required for a variable to reach the set point without overshooting.

ADEX Operator

When the user clicks on the ADEX Operator tab (see Figure 18), the ADEX Operator is displayed as shown in Figure 9.

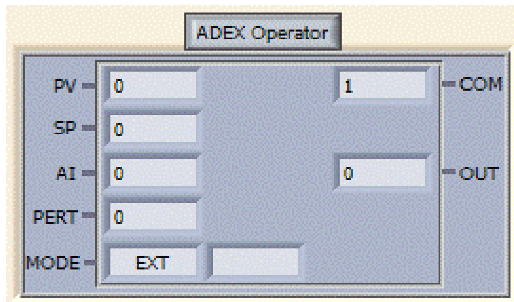


FIGURE 9 - DIAGRAM OF THE ADEX OPERATOR

It can be seen in the diagram that the ADEX Operator shows I/O values of the selected MISO controller in real time which are, in this case, PV1, SP1, AI1, PERT and OUT1 although the labels do not show the number 1 of the MISO. If the MISO controller number 2 was selected, the variables would have the number 2 attached (PV2, SP2, AI2 and OUT2. In addition, it can be seen that the ADEX operator displays two MODE variables. The left hand MODE variable is the signal received from the COL while the right hand one is an internal MODE variable which the user can put into “Auto” by clicking with the mouse. If this last option is taken, the control mode continues “External”, that is, the control signal OUT follows the actual input signal AI generated by the COL, but it puts into action a mode “Internal AP Control”.

The AP internal mode initiates the function of Adaptive Predictive Control, i.e. the Driver Block, the Control Block and the Adaptive Mechanism, although the Adaptive Predictive Control signal is not applied yet to the process. This mode of internal operation can be understood as a kind of “training” for the Adaptive Predictive Control before it is applied to the process. This allows the user to observe the evolution of the parameters and variables of the controller such as, for example, see how the Prediction Error (PE) tends to zero, and how the AP model converges on specific values. In this way, the user can easily adjust the system before the application of the AP control signal and ensure it is working appropriately and correctly.

Similarly, while the controller is under Auto control, the operator will be able to activate an “Internal Manual” (MAN) mode from the ADEX Operator, and an “Internal Set point” (INT.SP) to control the selected MISO controller. In the first instance, the operator can determine the output OUT of the controller by changing the corresponding field "OUT" of the ADEX controller from the keyboard. In this mode, the value of OUT will remain a constant if the operator does not change its value.

Under the "Internal Set point" mode, the operator can force the value of the Internal Set point (INT. SP) field which will become the new controller set point.

Configuration of other AP Domains

Once the configuration of the AP-C domains have been completed, the user can configure other AP domains. To do this, click in the box associated with the configuration domain indicated in Figure 2 shown in the next section. The user can configure a new domain such as upper (AP-U) or lower (AP-L).

Configuration of the Expert Domains

The user can configure an Expert Domain while in the window as shown in Figure 10. If the user clicks on the selected domain, for example EX-U, the system will display a screen like that shown in Figure 11.

In this case, only three blocks to be configured will be active i.e. Process, Expert and Control.

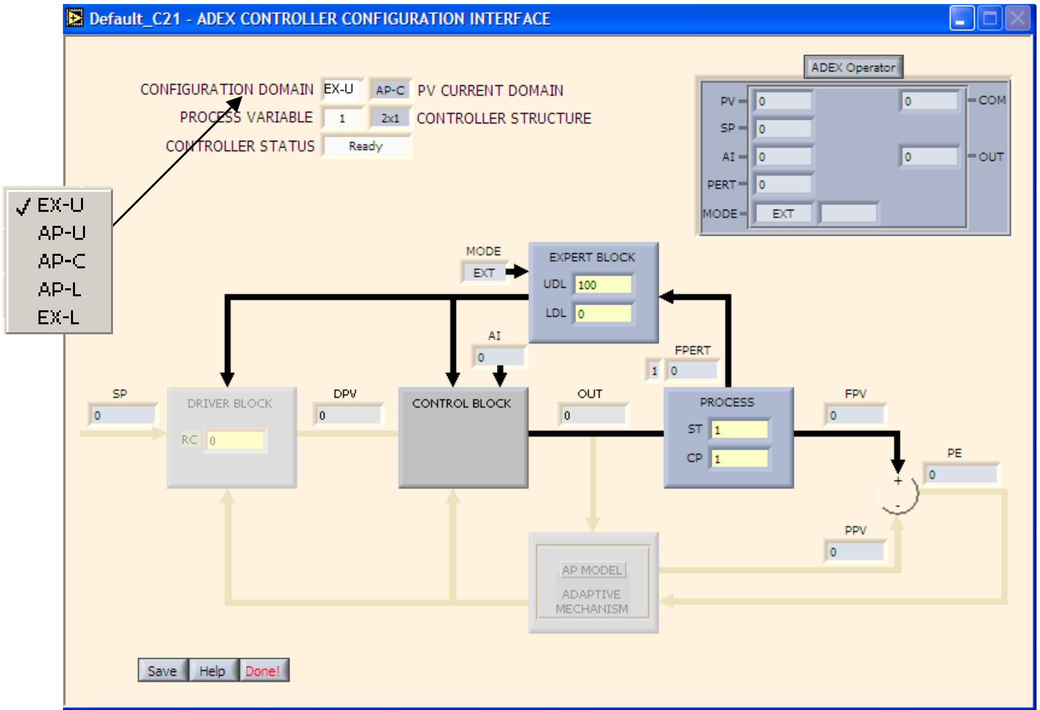


FIGURE 10 - CONFIGURING EXPERT DOMAINS

The value of the parameters shown in the Expert Block can be changed by the user in order to determine the upper (UDL) and lower (LDL) limits of the Expert Domain selected. The user can change the values of the Sampling Time (ST) and the Control Period (CP) for the selected domain in the Process Block as has been previously explained.

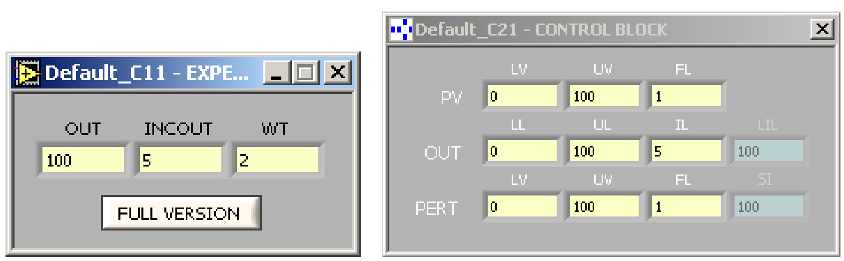


FIGURE 11 - CONFIGURATION OF THE EXPERT DOMAIN

If the Control Block is selected, two configuration windows are displayed, as shown in Figure 11.

The window to the right shows the default values of the range and filter variables (LV, UV and FL) in relation to the process variable (PV) and the ranges and incremental limits (LL, UL, IL) in relation to the output variable

(OUT) and perturbations if relevant (PERT). The user can make changes to all the parameters of the selected domain. These have all been described in previous sections.

The window to the left of Figure 28 shows the parameters of Expert Control. A button is displayed which changes the number of parameters used by the expert block. In a reduced version, only three are used and these are explained as follows in the context of the Expert Block:

- **OUT** - This is the value of the control signal which the ADEX controller, under Automatic mode, generates first while the selected PV is in the Expert Domain under consideration.

- **INCOUT** - This value will be added to the above control signal periodically if PV1 does not leave the expert domain.

- **WT** - Waiting time. This is the value of the time period in seconds which the system will wait prior to carrying out the incremental action in the control signal mentioned above in INCOUT.

Part II

Choice of Structure Variables

Introduction

As described before, ADEX methodology is applied to multivariable processes by decomposing internally the ADEX multivariable controllers into a set of n multi-input single-output (MISO) ADEX controllers. This section explains how to select the most significant structure variables in a MISO ADEX controller. Thus, the selection criteria presented here are valid for single-input single-output and multivariable controllers.

Control & Sampling Period

The selection of the control period for a MISO ADEX controller should be done, if possible, in the light of the dynamics of the process variable PV itself, and with particular attention to what we call the *response time* of the loop, a concept which is illustrated in Figure 12. Response time is defined as the time the process variable takes to enter a range (from ±5% of the value of the increment of PV) around its stationary state value, in response to a step in the OUT control signal. It is assumed that the step in the value of OUT will begin from a stationary state of the process.

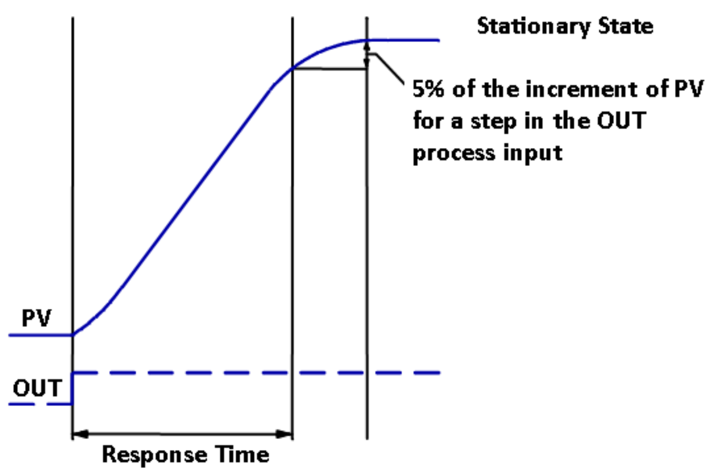


FIGURE 12

If the control period is very short with respect to the response time, the successive measurements of PV at the different control instants will contribute little information about the variation of PV, and, even worse, may contain measurement noise. Moreover, the b_i parameters of the AP model tend to zero as the control period diminishes. This makes the validity of prediction more sensitive than is desirable to identification errors and measurement noises. Likewise, the time delays of the different inputs of the MISO ADEX controller (DP), which are accounted in control periods, may excessively increase. It would be advisable to maintain these time delays under or equal 6 control periods.

If the control period is significantly long with respect to the response time, we cannot correct deviations of the PV produced during a control period until the next control instant arrives and this may take too long. Also, if the control period and sampling period are equal, we may lose information which would be useful for control purposes, since the variation of PV may be captured at intervals which will be too widely spaced, ignoring what happens between those intervals.

For all of the reasons set forth above, it is not advisable to choose a control period that is either very short or excessively long relative to response time.

In practice, it is recommended a control period for a MISO ADEX controller between 1/5 and 1/40 of the response time. The sampling period should be selected according to filtering criteria so that, if strong filtering is suitable, the sampling period should be short compared with the control period. Within the context of an ADEX multivariable controller, including more than one MISO ADEX controller, a compromise must be made for the control period selected.

Noise level

We advise setting the noise level NL as precisely as possible. When in doubt, it is more prudent to estimate NL on the broad side than on the narrow side. However, because the control action is moderated when PV is inside the noise level band, if the latter is unnecessarily broad, it can give rise to unacceptable deviations of PV with respect to the set point SP. In general, the process variable PV will tend to be in a band which, relative to the setpoint, will be lower than the noise level band.

Moreover, we must take into account that when the set point changes, the noise band will center itself around the new SP. If this change is not greater than the width of the noise level band, the process variable can remain inside it and, as a result, the control action will be moderated. The result may be that the PV does not converge towards the new SP.

Number of AP Model Parameters

If the time delays of the MISO ADEX controller inputs are fixed, the selection of number of parameters N for the different input/output AP model signals is simple; in most cases it will be made equal to 2. However, if the time delay is variable for the control signal, a number of parameters for this signal will be chosen which will allow the adaptive mechanism to adjust the corresponding b_i parameters to follow the variations of the time delay. To illustrate this procedure, let us consider a simple single-input single-output process in which the time delay of PV with respect to OUT can vary between 0 and 2. In this case we could choose the following predictive model:

$$PV(k+1|k) = A_1(k) \cdot PV(k) + A_2(k) \cdot PV(k-1) + B_1(k) \cdot OUT(k) + B_2(k) \cdot OUT(k-1) + B_3(k) \cdot OUT(k-2) \qquad (1)$$

Where N = 2 for PV, N = 3 for OUT and DP = 0.

If the actual time delay of the process (without considering the inherent time delay of discrete processes) is equal to zero, the identification mechanism will give the parameter $B_1(k)$ a value other than zero. Nonetheless, if the actual time delay of the process becomes equal to 2, identification will generate a model like this one:

$$PV(k+1|k) = A_1(k) \cdot PV(k) + A_2(k) \cdot PV(k-1) + 0 \cdot OUT(k) + 0 \cdot OUT(k-1) + B_3(k) \cdot OUT(k-2) \qquad (2)$$

That is, B1 and B2 will have been made equal to 0, revealing that the actual time delay is equal to 2. Therefore, if we want to retain at least one B_i which is not equal to zero, it is advisable to choose DP and N for OUT in the following manner:

$$DP = DP_{min}$$

$$N \geq DP_{max} - DP_{min} + 1$$

Where DP_{min} and DP_{max} are the minimum and maximum limits, respectively, of the range of possible variation of the actual time delay.

In the AP model, the number of actual time delays of OUT over PV, which in fact occurs, will be defined by the equation:

$$DP\ efectivo = DP_{min} + \text{número de } B_i \text{ iguales a 0}$$

In the most unfavorable case, in which the number of actual time delays of OUT over PV would be equal to DP_{max}, there would still be a B parameter to identify the process dynamics.

An analogous consideration is valid for the number of parameters related to other input signals within the AP model of a MISO ADEX controller.

Initial Values for the AP Model Parameters

Let us consider a stable linear single-input single-output process described by the following equation:

$$PV(k+1) = A_1 \cdot PV(k) + A_2 \cdot PV(k-1) + B_1 \cdot OUT(k) + B_2 \cdot OUT(k-1) \quad (3)$$

Assuming initial values equal to zero, the process gain can be calculated from the permanent response PV_{perm} to a step in the control signal OUT_{step}, by means of:

$$G = PV_{perm} / OUT_{step}$$

Since equation (3) will also be verified when the steady state is reached by the process, after the application of said step in the control signal, it may be written:

$$PV_{perm} = A1 \cdot PV_{perm} + A2 \cdot PV_{perm} + B_1 \cdot OUT_{step} + B2 \cdot OUT_{step} + B3 \cdot OUT_{step} \quad (4)$$

Therefore, by dividing both members of (4) by OUT_{step}:

$$G = A_1 \cdot G + A_2 \cdot G + B_1 + B_2 + B_3 \quad (5)$$

$$G = \Sigma B_i / (1 - \Sigma A_i) \quad (6)$$

The preceding equation can be useful to us for establishing some initial or default values for the AP model parameters which would comply themselves with a experimental estimation of the process gain.

As an example, let us assume an AP model described by the following equation:

$$PV(k+1|k) = A_1(k) \cdot PV(k) + A_2(k) \cdot PV(k-1) + B_1(k) \cdot OUT(k) + B_2(k) \cdot OUT(k-1) \qquad (7)$$

If the gain of this process is equal to 1, we could take the following as initial or default values for the parameters of the predictive model:

$A_1(0) = 1$ $\qquad B_1(0) = 0.1$

$A_2(0) = -0.2$ $\qquad B_2(0) = 0.1$

In fact, these are typical initial or default values for the predictive model of ADEX controllers. We can see that equation (6), which relates gain with the model parameters, is fulfilled:

$$G = \frac{0.1 + 0.1}{1 - 1 + 0.2}$$

If the gain were different from 1, it would be sufficient to multiply all the B parameters by the value of the gain to obtain a predictive model with the appropriate gain.

In general, the adaptive mechanism of ADEX controllers will find the appropriate value for the predictive model parameters by itself. Nevertheless, for reasons of common sense and to facilitate adaptation, it is obviously a good idea to initialize the parameters of the predictive model in such a way that the model has a gain that is approximately equal to or greater than the process gain, so that the first control signals are correctly moderated when the model is not yet adapted. Further, the rational choice of other structure variables, such as the prediction horizon considered in the next section, makes the ADEX controller performance robust and tolerant of errors in the identification of predictive model parameters.

As a general rule, it should be borne in mind that, if the control period tends toward zero, the Bi parameters of the process will also tend toward zero. Moreover, when the control period tends toward to the response time, the B_1 parameter tends toward the gain G, and the rest of the Ai and

Bi parameters tend toward zero. This dependency of the parameter values on the control period is inherent to the mathematical representation of the process, and may be observed in parameters identification performed by the adaptive mechanism of ADEX controllers.

An analogous consideration is valid for the choice of the initial or default values of the parameters related to other inputs signals within the AP model a MISO ADEX controller.

Prediction Horizon

When the Prediction Horizon PH is small, the process variable PV is constrained to follow closely the desired trajectory, without taking into account the actual dynamics of the process. On the other hand, when PH is bigger the process variable can reach the desired values with more flexibility taking into account the actual process dynamics.

Thus, the selection of PH depends on the rigor with which we want the process variable PV to follow, step by step, a given path or desired trajectory. If PH is small or equal to 1 (its minimum value), the possible measurement noise in PV(k) can introduce high frequency contents in the control signal OUT.

Also, it is important to consider that the prediction horizon must compensate for the variations of pure time delays when they occur. As considered previously in Section 4, for a process time delay which varies between DP_{min} and DP_{max}, the structure variable DP will be set equal to DP_{min} and the difference with the actual time delay of the process will be absorbed by a certain number of parameters B which become equal to zero. In this case the PH must choose:

$$PH \geq DP_{max} - DP_{min} + 1 \qquad (8)$$

This is due to the fact that when the actual process time delay becomes equal to DP_{max} , if inequality (8) is not verified, the prediction instant k + DP + PH will be previous to the instant k + DP_{max} + 1, that is the first instant in which the control action OUT applied at instant k will have an effect on the process variable PV, and as a consequence the application of predictive control will not be possible.

An analogous consideration must also be made for the choice of PH in relation with other input signals with variable time delays within the AP model of a MISO ADEX controller.

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