

## Chapter 12: Appendix E - Description of Software

The name of the executable file to run the program is *MillControll.exe*. Before running the program, the Active-X control named *TraceX.ocx* first needs to be registered. This is done by copying the *tracex.ocx* file to the *c:\windows\system* directory. Next, click on the *Start*-button and go to the *Run*-option. In the edit box, type *regsvr32 TraceX.ocx* to register the Active-X control file.

The three text files in which the values of the parameters are stored, are *MPCParam.TXT*, *Param.TXT* and *Weight.TXT*. *MPCParam* stores the MPC-controller parameters, *Param* stores the simulator parameters and *Weight* stores the weighting matrices of the MPC-controller. Starting up the program, the following window will appear (Figure 12-1):

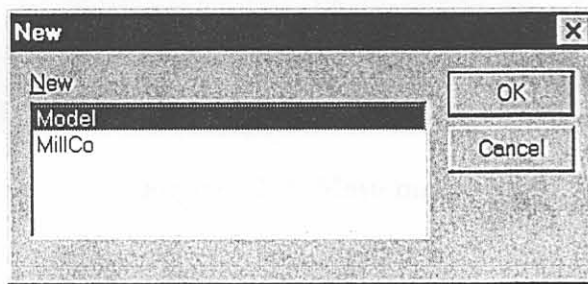


Figure 12-1: Start-up

Select *Model* and click on the *OK* button. The main menu window will then appear (Figure 12-2). If *MillCo* is selected, a blank window will appear without the simulator.

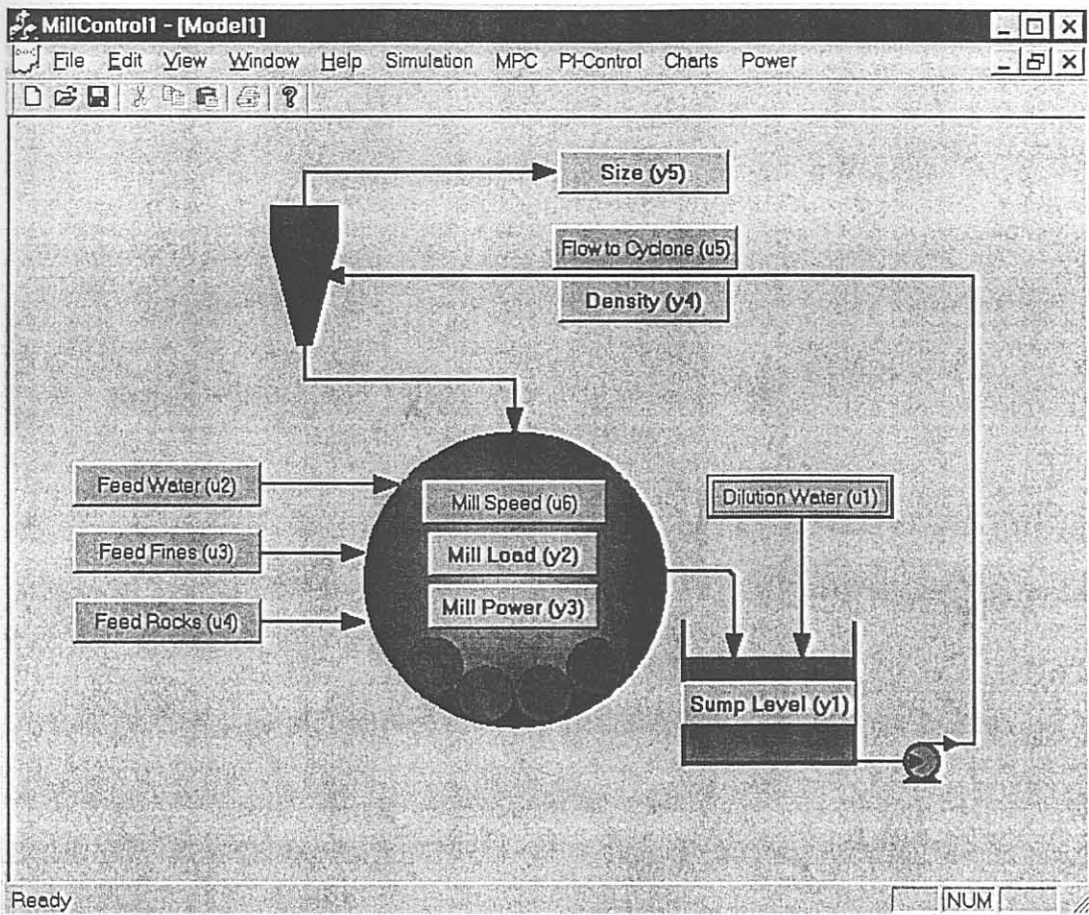


Figure 12-2: Main menu

The parameters of the input module are specified by clicking on any of the input parameters ( $u$ ). The window in Figure 12-3 will appear for each input.



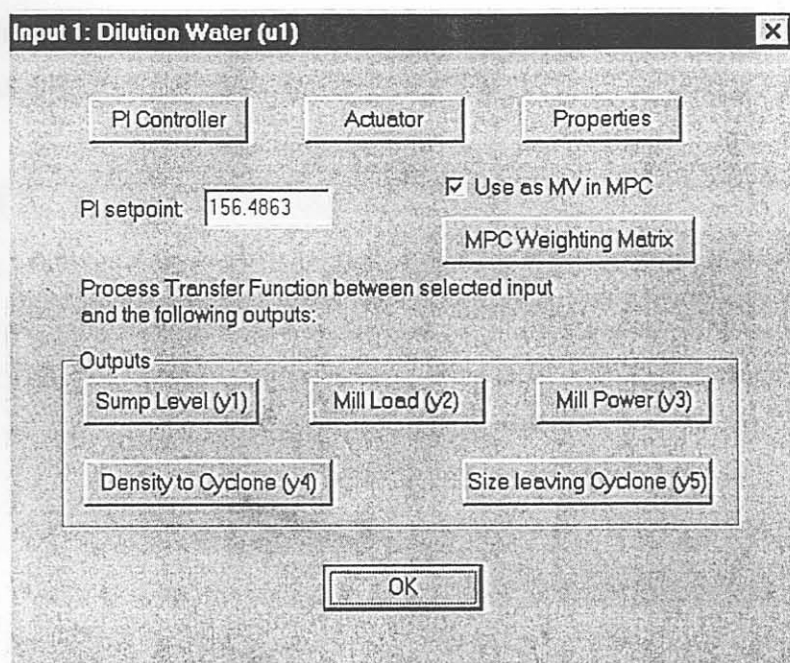


Figure 12-3: Input module

On this window all the parameters for this specific input (*Dilution water  $u_1$* ) can be specified. First, the setpoint of the local PI-controller can be changed by clicking on the *PI Controller* button. This will produce the following window (Figure 12-4):

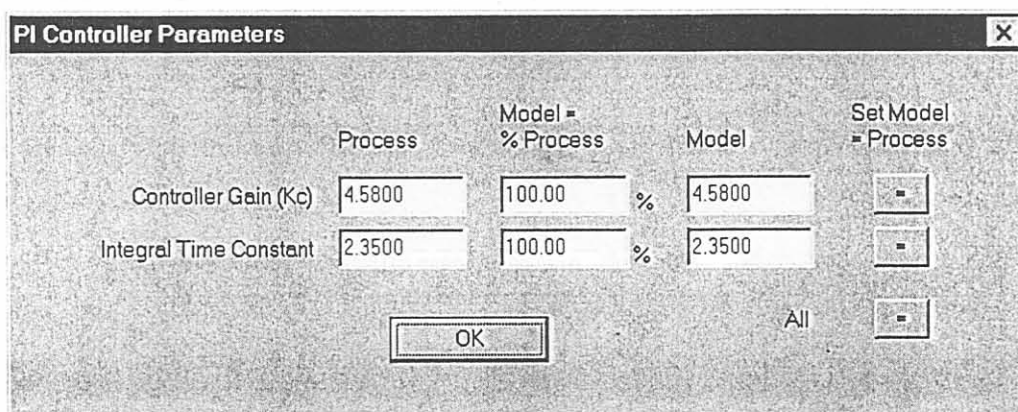
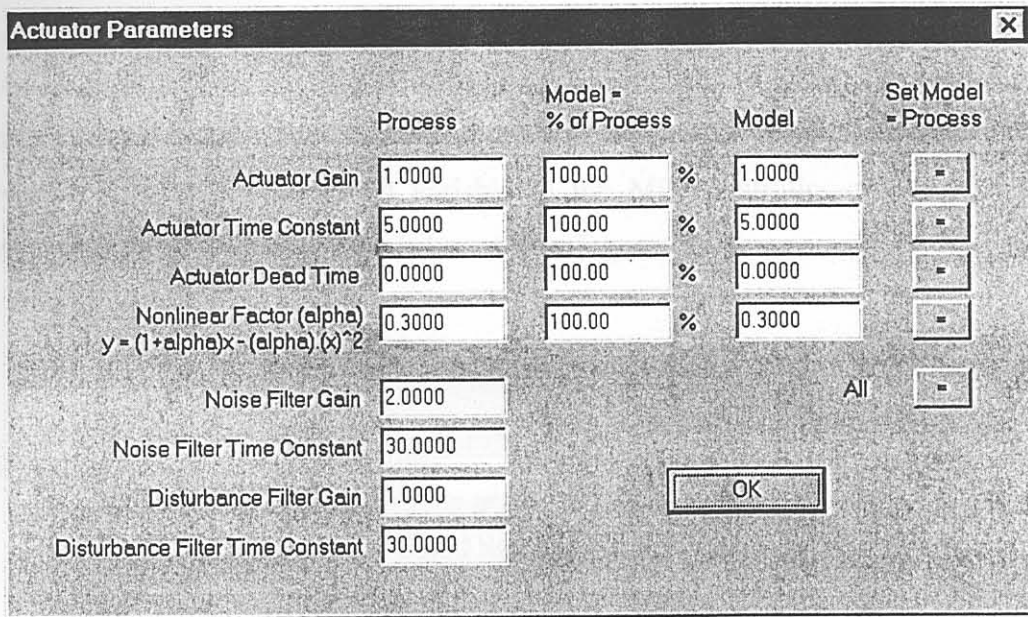


Figure 12-4: PI-controller parameters

The controller gain ( $K_c$ ) and the integral action of the PI-controller can be specified. The parameters that are used to create the model in the MPC-controller can be made to differ with a certain percentage from the real process. By pressing on the “=”-button, the model is set equal to the process. When finished, the *OK* button is pressed to return to the input module window (Figure 12-3). The parameters of the actuator as well as the extent of the



measurement noise and disturbance can be entered next by clicking on the *Actuator* button (producing Figure 12-5).

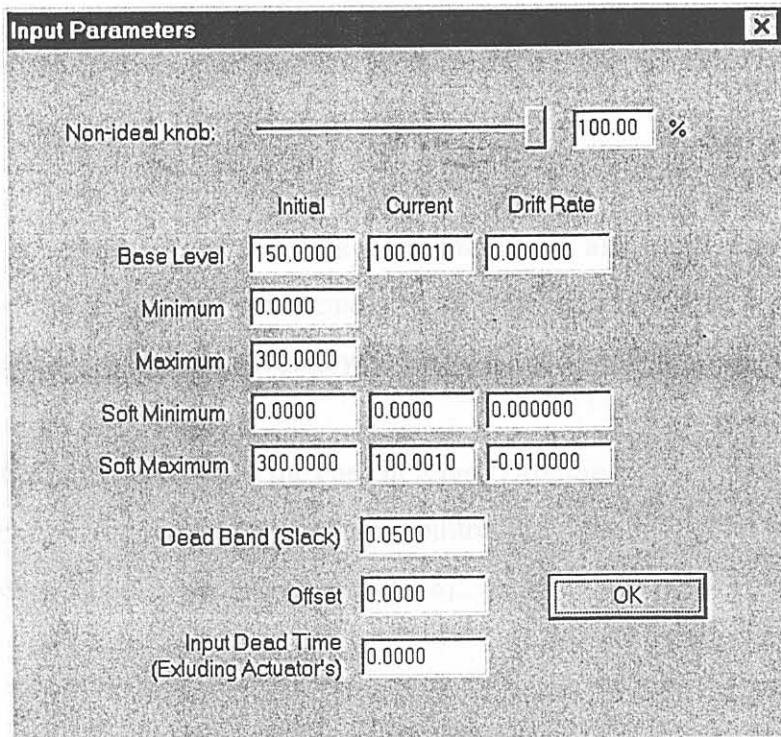


	Process	Model = % of Process	Model	Set Model = Process
Actuator Gain	1.0000	100.00 %	1.0000	<input type="checkbox"/>
Actuator Time Constant	5.0000	100.00 %	5.0000	<input type="checkbox"/>
Actuator Dead Time	0.0000	100.00 %	0.0000	<input type="checkbox"/>
Nonlinear Factor (alpha) $y = (1+\alpha)x - (\alpha)(x)^2$	0.3000	100.00 %	0.3000	<input type="checkbox"/>
Noise Filter Gain	2.0000		All	<input type="checkbox"/>
Noise Filter Time Constant	30.0000			
Disturbance Filter Gain	1.0000			
Disturbance Filter Time Constant	30.0000			

OK

Figure 12-5: Actuator parameters, noise and disturbances

The rest of the input parameters (minimum, maximum, base level, drift rates etc.) are specified by clicking on the *Parameters* button (see Figure 12-6).



Non-ideal knob:  100.00 %

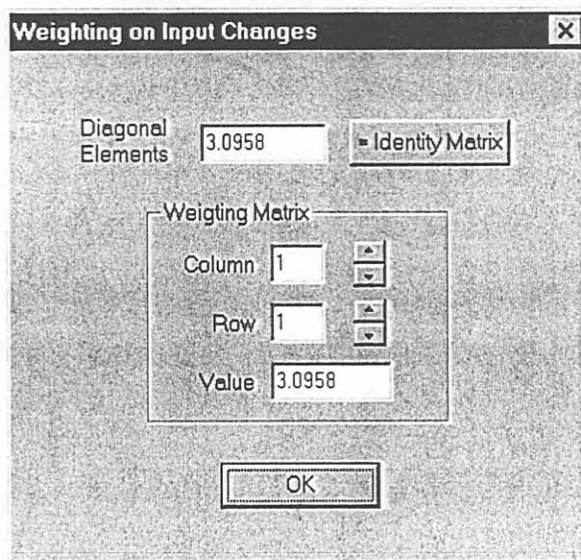
	Initial	Current	Drift Rate
Base Level	150.0000	100.0010	0.000000
Minimum	0.0000		
Maximum	300.0000		
Soft Minimum	0.0000	0.0000	0.000000
Soft Maximum	300.0000	100.0010	-0.010000
Dead Band (Slack)	0.0500		
Offset	0.0000		
Input Dead Time (Excluding Actuator's)	0.0000		

OK

Figure 12-6: Other input parameters

The non-ideal multiplier *knob* for the inputs is specified here to determine the extent of the nonlinearities.

The *Use as MV in MPC* check box in Figure 12-3 specifies whether this particular input should be used as a manipulated variable in the MPC-controller. If this check box is checked, the weighting for this manipulated variable in the MPC-controller can be specified by clicking on the *MPC Weighting Matrix* button (see Figure 12-7).



**Figure 12-7: Weighting matrix for manipulated variables ( $W_2$ )**

All the diagonal elements can be changed simultaneously by changing the value in the *Diagonal Elements* edit box. The elements in the matrix can also be changed individually by selecting the row and column of the element to be changed and entering a new value. The matrix can be reset to the identity matrix by clicking on the “= Identity Matrix” button.

Lastly the transfer function between the current input (*Dilution Water*  $u_1$ ) and each of the five outputs can be entered by clicking on an output button in Figure 12-3. The following window will appear for each input-output pair (Figure 12-8):



State: Dilution Water (u1) -> Sump Level (y1)

Choose Transfer Function:

$[a + (b) \cdot (\tau) \cdot (s)] / [1 + (\tau) \cdot (s)]$   
  $a / s$

Properties OK

	Process	Model = % of Process	Model	Set Model = Process
Steady State Gain (a)	0.0025	100.00 %	0.0025	<input type="button" value="-"/>
Immediate Response Gain (b)	0.0000	100.00 %	0.0000	<input type="button" value="-"/>
First Order Time Constant ( $\tau$ )	0.0000	100.00 %	0.0000	<input type="button" value="-"/>
Dead Time	0.0000	100.00 %	0.0000	<input type="button" value="-"/>
			All	<input type="button" value="-"/>

Figure 12-8: State module

A selection can be made between a first order transfer function or a pure integrator by selecting the appropriate radio button. A distinction can also be made between the transfer function of the process and the transfer function of the model used in the MPC controller. This can be used to test model errors. The state parameters can be entered by clicking on the *Properties* button (see Figure 12-9).

State Parameters

Non-ideal knob:  %

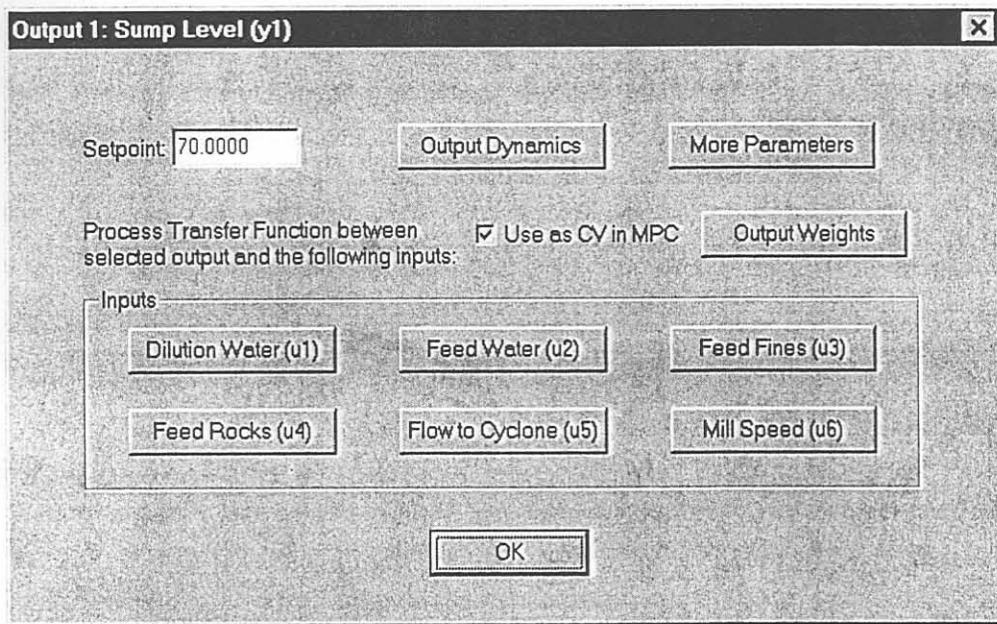
	Initial	Current	Drift Rate
Base Level	0.0000	0.0000	0.000000
Minimum	-1000000.00		
Maximum	1000000.000		
Soft Minimum	-1000000.00	-1000000.00	0.000000
Soft Maximum	1000000.000	1000000.000	0.000000
Disturbance Filter Gain	0.0000		
Disturbance Filter Time Constant	0.0000		

OK

Figure 12-9: State Parameters



The output parameters are specified by clicking on any of the outputs on the main window (Figure 12-2). Figure 12-10 will appear for each output.



**Output 1: Sump Level (y1)**

Setpoint: 70.0000    Output Dynamics    More Parameters

Process Transfer Function between selected output and the following inputs:  Use as CV in MPC    Output Weights

Inputs

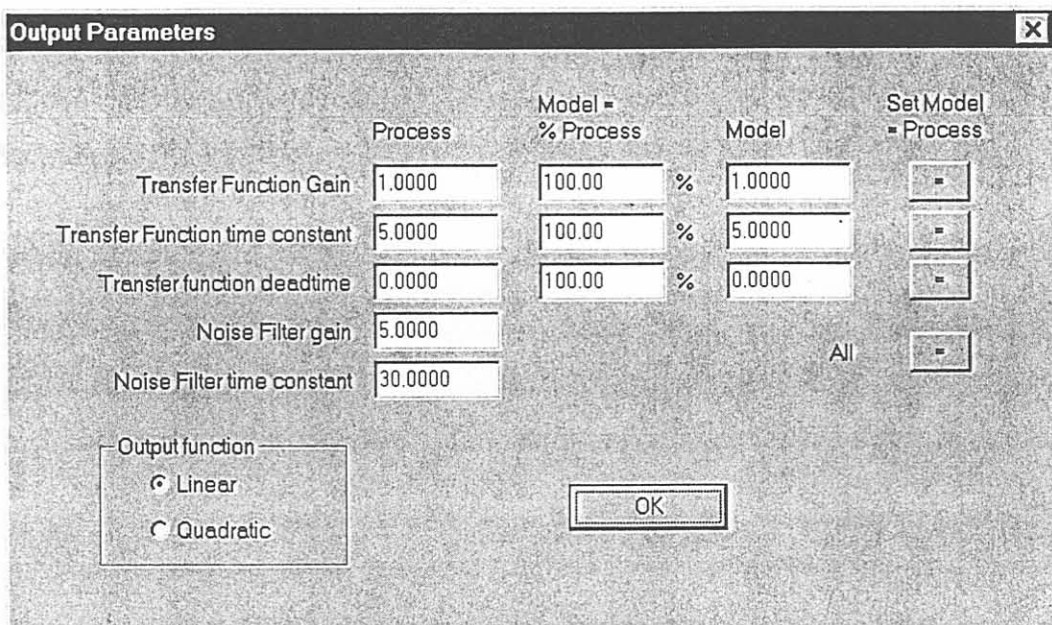
Dilution Water (u1)    Feed Water (u2)    Feed Fines (u3)

Feed Rocks (u4)    Flow to Cyclone (u5)    Mill Speed (u6)

OK

Figure 12-10: Output Module

The setpoint for the main controller of this specific output (*Sump level*  $y_1$ ) can be specified here. The dynamics of the output module and the noise can be specified by clicking on the *Output Dynamics* button (producing Figure 12-11).



**Output Parameters**

	Process	Model = % Process	Model	Set Model = Process
Transfer Function Gain	1.0000	100.00 %	1.0000	-
Transfer Function time constant	5.0000	100.00 %	5.0000	-
Transfer function deadtime	0.0000	100.00 %	0.0000	-
Noise Filter gain	5.0000			All -
Noise Filter time constant	30.0000			

Output function

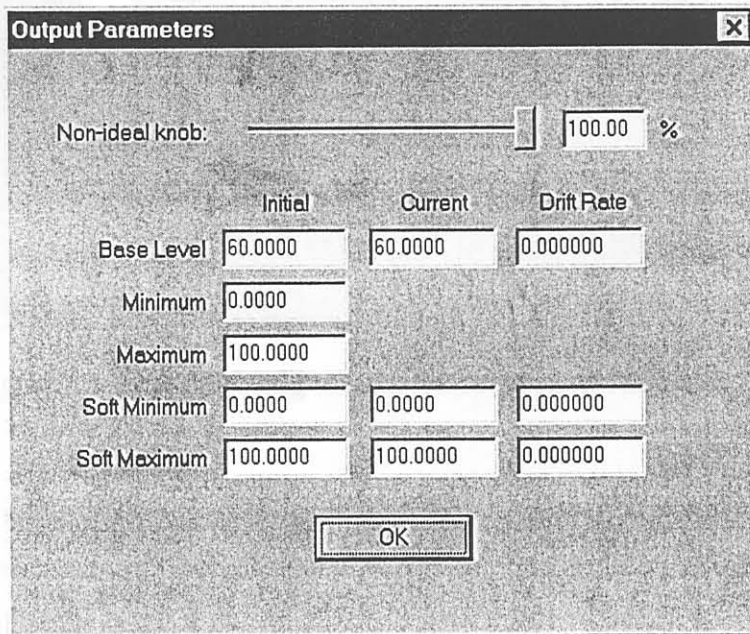
Linear

Quadratic

OK

Figure 12-11: Output dynamics

A choice can be made whether the output should be computed by adding the effect of all the inputs on this output linearly or squaring the sum (quadratic) by clicking on the appropriate radio button. The other parameters (minimum, maximum, base level, drift rates etc.) can be specified by clicking on the *More Parameters* button (Figure 12-12).



	Initial	Current	Drift Rate
Base Level	60.0000	60.0000	0.000000
Minimum	0.0000		
Maximum	100.0000		
Soft Minimum	0.0000	0.0000	0.000000
Soft Maximum	100.0000	100.0000	0.000000

Figure 12-12: Output parameters

The *Use as CV in MPC* check box specifies whether this particular output should be controlled using the MPC controller. If this output is controlled, the weighting matrix for constraining this particular controlled variable can be changed by clicking on the *Output Weights* button.



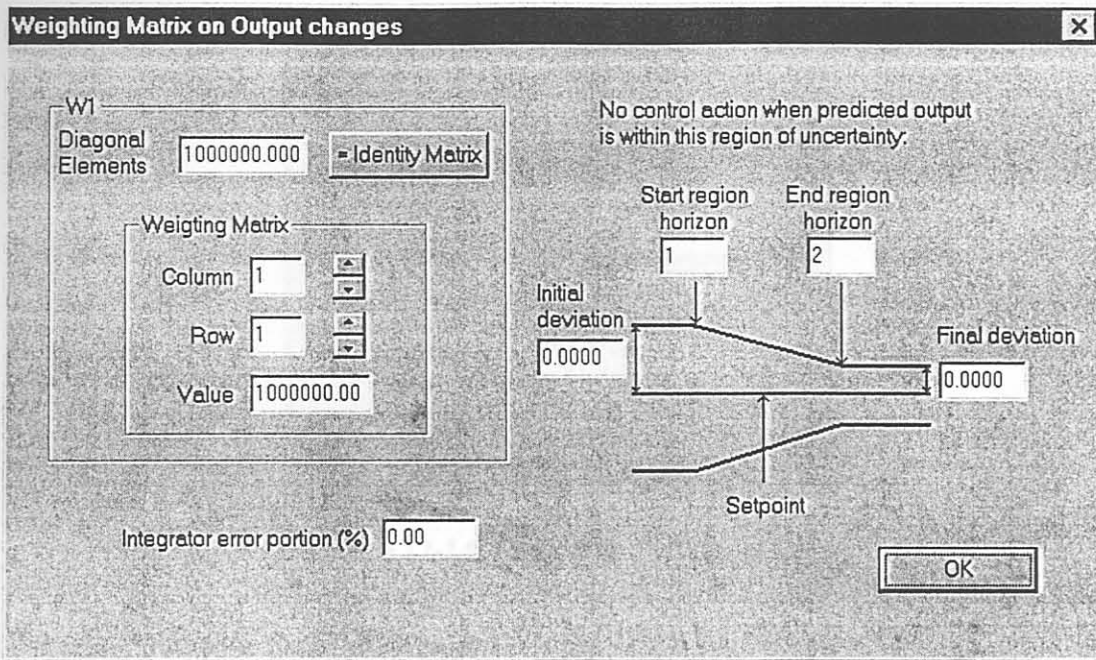
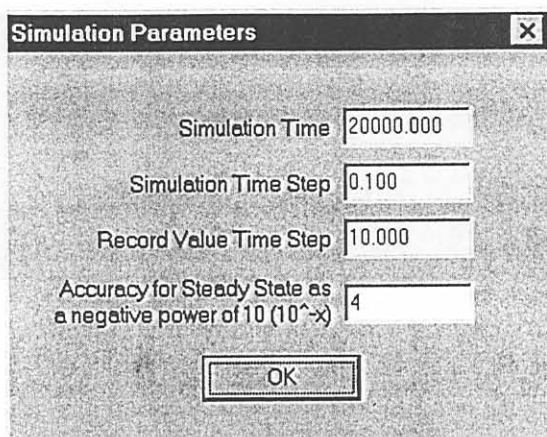


Figure 12-13: Weighting matrix for controlled variables ( $W_1$ )

This window functions in exactly the same manner as the one for the input weights (Figure 12-7). It furthermore has additional properties that can be set, like the region of uncertainty parameters and the portion of the error that is contributed to integral error. The form of the region is shown on this window. The initial and final deviation of the region from the setpoint is specified in the appropriate edit boxes. The horizon at which the sloping of the region should start and end is also specified in terms of multiples of the controller time step. The minimum for the *Start region horizon* is 1 and the maximum for the *End region horizon* is equal to the prediction horizon ( $V$ ). The *End region horizon* should furthermore always be larger than the *Start region horizon*. If one of these limits is violated, the program will automatically set the value equal to the limit.

The transfer function between this output and any of the six inputs can now again be accessed by clicking on the appropriate input (in this case the transfer function is therefore approached from the other side, that is from the outputs). The same window as in Figure 12-8 will appear for the selected output-input pair.

After entering all the parameters for the milling circuit, the simulation parameters can be specified next. This is done by clicking on *Change Parameters* in the *Simulation* pull-down menu, which will produce Figure 12-14.



Simulation Parameters

Simulation Time: 20000.000

Simulation Time Step: 0.100

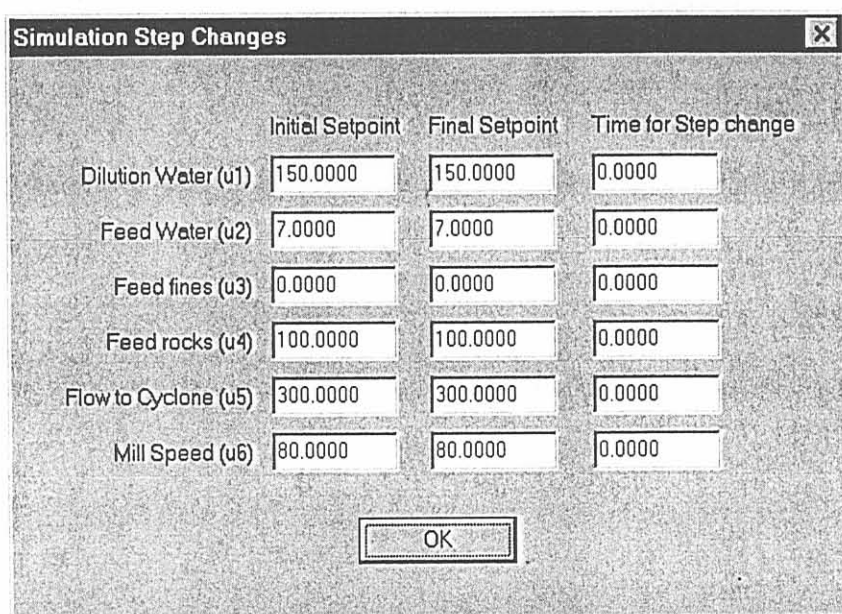
Record Value Time Step: 10.000

Accuracy for Steady State as a negative power of 10 ( $10^{-x}$ ): 4

OK

Figure 12-14: Simulation parameters

Step changes to the setpoints of the local PI-controllers can be specified by clicking on *Step Changes* in the *Simulation* pull-down menu (Figure 12-15).



Simulation Step Changes

	Initial Setpoint	Final Setpoint	Time for Step change
Dilution Water (u1)	150.0000	150.0000	0.0000
Feed Water (u2)	7.0000	7.0000	0.0000
Feed fines (u3)	0.0000	0.0000	0.0000
Feed rocks (u4)	100.0000	100.0000	0.0000
Flow to Cyclone (u5)	300.0000	300.0000	0.0000
Mill Speed (u6)	80.0000	80.0000	0.0000

OK

Figure 12-15: Simulation step changes

The milling circuit can now be simulated without being controlled by selecting the *Run Simulation* option in the *Simulation* pull-down menu. Step changes will be applied during the simulation as specified in the *Simulation Step Changes* window (Figure 12-15). If the simulation has run before, the user will be asked if the simulation should be reset (see Figure 12-16):



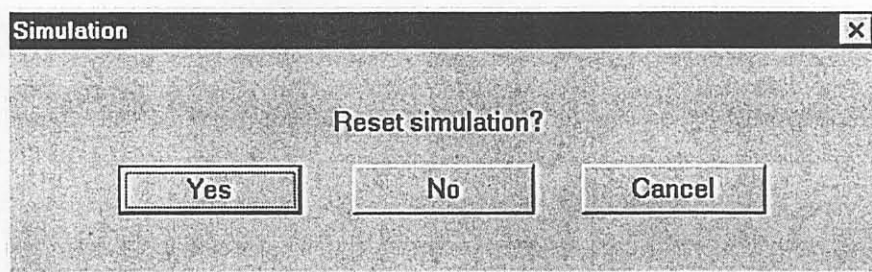


Figure 12-16: Reset simulation

If *Yes* is clicked, the simulation will restart from time zero and the same step changes will be applied as specified in the *Simulation Step Changes* window. If *No* is selected, the simulation will continue from where it stopped previously and no step changes will be applied. If *Cancel* is pressed, no simulation will be performed. When the simulation is finished, a window will appear to graph the output as a function of time (Figure 12-17). The outputs can be displayed by clicking on the *Refresh* button. If the simulation is a continuation of a previous simulation, each next simulation is displayed by pressing the *Refresh* button repeatedly.

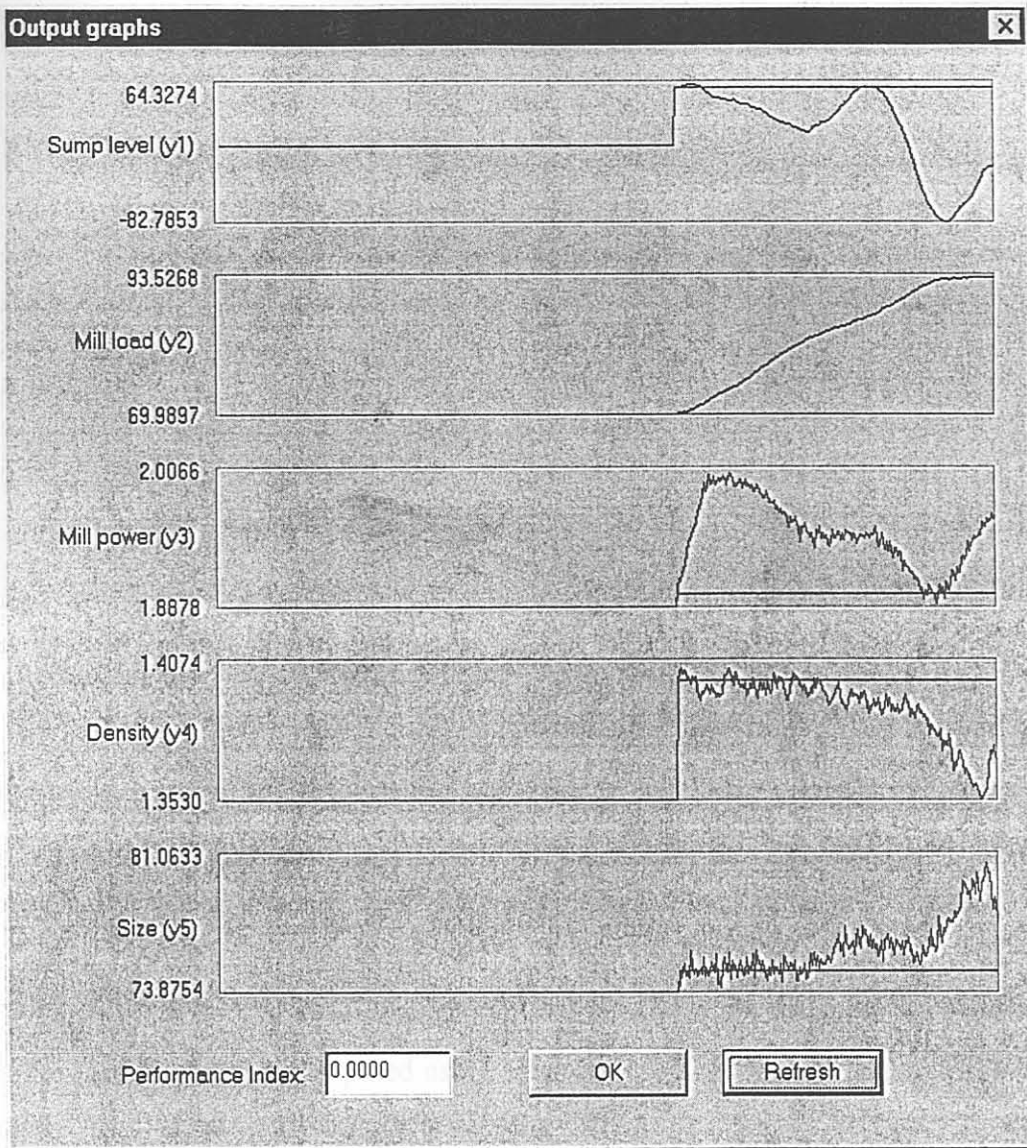


Figure 12-17: Graphs of outputs

The MPC-controller parameters can be specified by clicking on the *Parameters* option in the *MPC* pull-down menu (Figure 12-18).



**MPC Parameters** [X]

Least Squares   
  Quadratic Programming   
 [Auto Tune]

Inputs					Outputs				
	Control Horizon (U)		MV	Feed-forward		Model Horizon (T)	Prediction Horizon (V)		CV
Dilution water (u1)	43 [Default]	[W2]	<input checked="" type="checkbox"/>	<input type="checkbox"/>	Sump level (y1)	100 [Default]	59 [Default]	[W1]	<input checked="" type="checkbox"/> [QP]
Feed water (u2)	32 [Default]	[W2]	<input type="checkbox"/>	<input checked="" type="checkbox"/>	Mill load (y2)	19 [Default]	41 [Default]	[W1]	<input checked="" type="checkbox"/> [QP]
Feed fines (u3)	4 [Default]	[W2]	<input type="checkbox"/>	<input type="checkbox"/>	Mill power (y3)	0 [Default]	38 [Default]	[W1]	<input type="checkbox"/> [QP]
Feed rocks (u4)	15 [Default]	[W2]	<input checked="" type="checkbox"/>	<input type="checkbox"/>	Density (y4)	100 [Default]	118 [Default]	[W1]	<input type="checkbox"/> [QP]
Flow to Cyclone (u5)	100 [Default]	[W2]	<input checked="" type="checkbox"/>	<input type="checkbox"/>	Size (y5)	25 [Default]	78 [Default]	[W1]	<input checked="" type="checkbox"/> [QP]
Mill Speed (u6)	4 [Default]	[W2]	<input type="checkbox"/>	<input checked="" type="checkbox"/>					

Sampling period: 35.7938 [Default]

Use Inputmodule in Model   
 [OK]

Use plant parameters for Model

Figure 12-18: MPC parameters

A choice can be made whether to use the *least squares* method or *quadratic programming* for the MPC-controller by clicking on the appropriate radio button. The inputs and outputs used in the MPC-controller can be specified by clicking in the check box under *MV* or *CV* respectively. The model horizon ( $T$ ) and Prediction horizon ( $V$ ) for each output can be specified, as well as the Control horizon ( $U$ ) for each input. By pressing on the default button, a value for the parameter is computed using rules of thumb. The weighting matrix to penalise the movement of each controlled variable (output) can be changed by clicking on the  $W1$  buttons. The same window as in Figure 12-7 will appear. The weighting matrix to penalise the movement of the manipulated variables (inputs) can be changed by clicking on the  $W2$  buttons (producing the window in Figure 12-13). If the *Quadratic Programming* option is selected, further parameters for each output can be specified by clicking on the  $QP$  buttons. Figure 12-19 will appear.

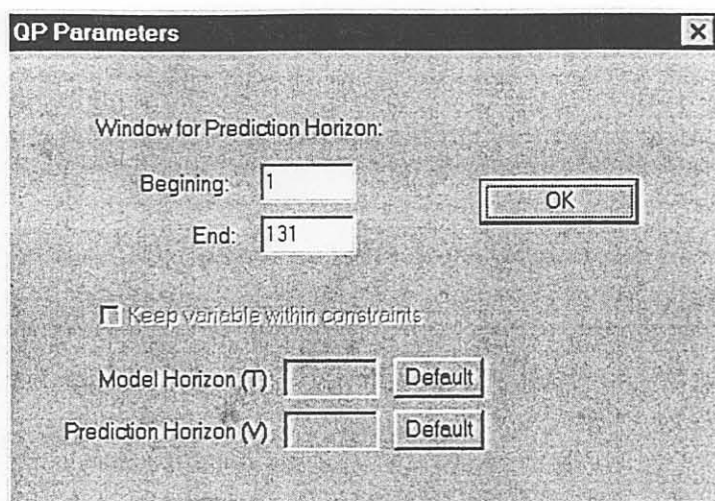


Figure 12-19: Quadratic programming parameters

If the output is being controlled by the MPC-controller using quadratic programming, the start and end times of the future predicted values that have to be kept within the constraints need to be specified. The beginning and end of the window is specified as a multiple of the sampling interval of the controller. If the output is not controlled by the MPC-controller, it can still be kept within its constraints by the MPC-controller by clicking on the *Keep variable within constraints* check box. The model and control horizons for this variable then also need to be specified.

The parameters can be tuned automatically by clicking on the *Auto Tune* button (producing Figure 12-20).



**Auto-Tuner** [X]

Integral of the Square Error  
 Integral of the absolute value of the error  
 Integral of the time weighted absolute error

Time for optimisation:

	Minimum % Change	Maximum value	Tune?
Model Horizon (T):	<input type="text" value="0.0000"/>	<input type="text" value="100"/>	<input checked="" type="checkbox"/>
Control Horizon (U):	<input type="text" value="0.0000"/>	<input type="text" value="100"/>	<input checked="" type="checkbox"/>
Prediction Horizon (V):	<input type="text" value="0.0000"/>	<input type="text" value="200"/>	<input checked="" type="checkbox"/>
W1:	<input type="text" value="1000000.00"/>	<input checked="" type="checkbox"/>	
W2:	<input type="text" value="1000000.00"/>	<input checked="" type="checkbox"/>	
Lower limit of constraint window for V (QP):	<input checked="" type="checkbox"/>		
Upper limit of constraint window for V (QP):	<input checked="" type="checkbox"/>		

Weighting for controller tuning  
(Relative importance of each CV)

Sump level (y1)

Mill load (y2)

Mill power (y3)

Density to Cyclone (y4)

Size out of Cyclone (y5)

Tune time step  
 Use Default values

Number of iterations

Figure 12-20: Auto-tuner

A choice can be made between using the *Integral of the square error*, the *Integral of the absolute value of the error* or the *Integral of the time weighted absolute error* as a error function when optimising for the best parameters. The time that each simulation has to be run for the optimisation is also specified. Each simulation is performed using the time step specified in the *Simulation Parameters* window. Each parameter that must be optimised can be selected by clicking on the corresponding check box. Maximum values for some parameters need to be specified, as well as a minimum change in the error that will be tolerable if the parameter is decreased. This option is incorporated to prevent the optimiser from increasing the parameters, and therefore also the computational time, if the error is not decreased substantially. The relative importance of each controlled variable can also be specified by changing their weighting. The contribution of each output error to the total error (performance index) is therefore specified by these parameters. If *OK* is pressed, the program starts optimising (which may take a long time). If *Cancel* is pressed, the program does not perform the optimisation.

By selecting the *Power* option on the menu bar (See Figure 12-2), Figure 12-21 will appear. The *Power Controller* can now be switched on or off by clicking in the check box in this

window. The time interval for the power controller and the amount by which the *Load* setpoint should be changed at each controller interval can also be specified in the appropriate edit boxes.

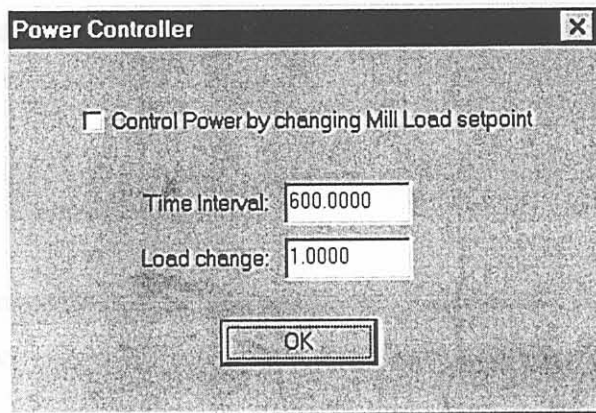


Figure 12-21: Power Controller