How To Use Adaptive Inverse Control (AIC) **BKT 15-Jan-10**

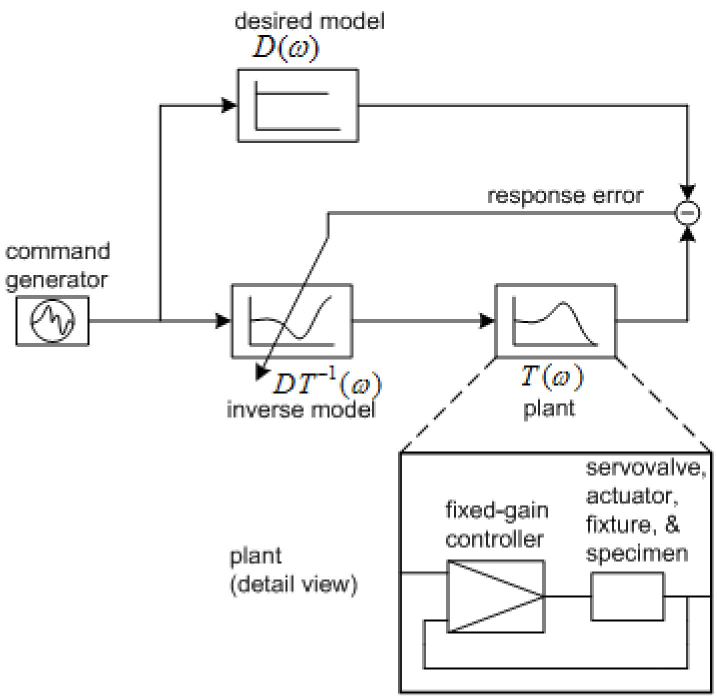
Adaptive Inverse Control (AIC) is a control compensation technique that augments a fixed-gain controller to correct for closed-loop gain and phase irregularities in order to improve control fidelity. In addition, in multichannel control systems with cross-coupled dynamics, it greatly reduces cross-coupling disturbances between control channels. It measures control system dynamics directly and modifies the control compensation accordingly in realtime, making it possible to adapt to changing system dynamics.

AIC is optimized to work with non-sinusoidal command waveforms and predominantly linear systems. If the command waveform is a pure sine wave, Amplitude/Phase Control (APC) works better and is easier to use. If the system has significant nonlinearities, you can augment AIC with Online Iteration (OLI).

How AIC works

Adaptive Inverse Control (AIC) is a control technique that improves the input-output frequency response of a control system. A control system must have a frequency response of unity magnitude and zero phase at all frequencies in order to achieve perfect control fidelity. In reality this is never achieved; peaks and valleys in the magnitude response and phase shifts conspire to cause discrepancies between command and feedback. AIC fixes up the overall frequency response so that the magnitude response is unity, and although it cannot make the phase response zero, it linearizes it so the overall frequency response looks like a simple delay.

AIC is shown schematically below:

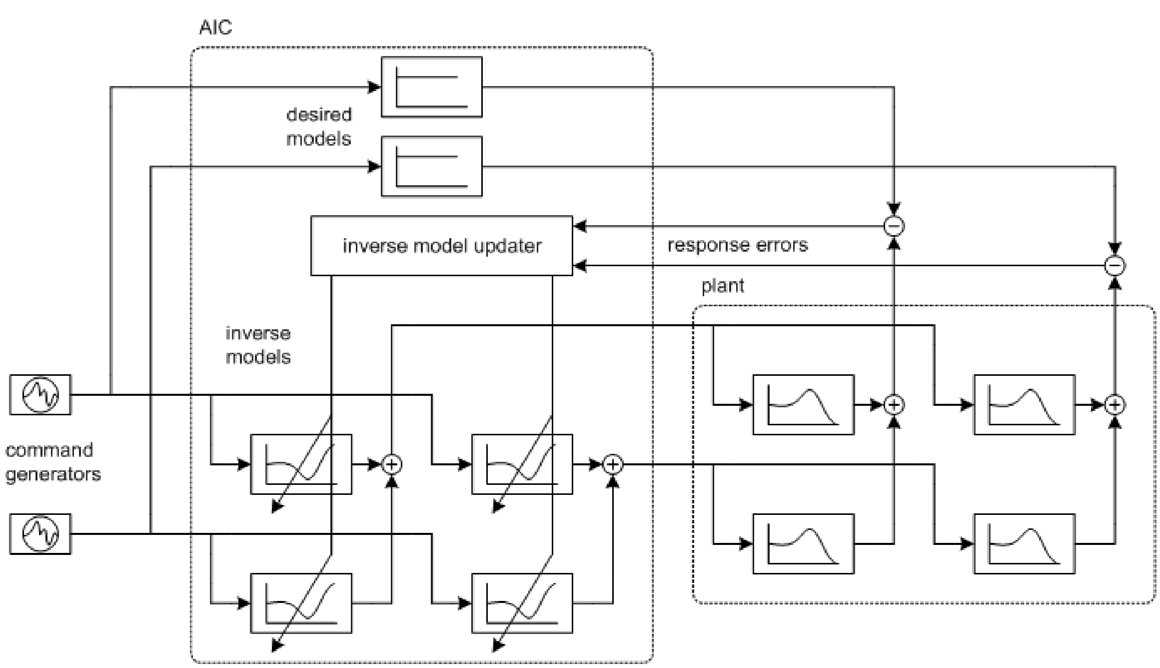


Ideally we would like the transfer function between command and plant response to be $D(\omega)$ rather than $T(\omega)$, which represents the dynamics of the fixed-gain controller, actuator, fixture, and test specimen combination hereafter called the *plant*. When AIC's inverse model is placed between the command generator output and the plant input, the inverse model cancels the plant dynamics, and the overall transfer function becomes $D(\omega)$. The inverse plant transfer function $T^{-1}(\omega)$ is not known in advance, so it is computed online by driving the desired model with the command generator, comparing its response to the response of the actual plant, and adjusting the inverse model to drive the response error to zero. When the response error is zero, the response of the inverse model/plant combination is indistinguishable from the response of the desired model, which is the intended result.

In general the desired model can be anything, but restrictions apply if a useful control result is to be obtained. If $D(\omega) = 1$, AIC attempts to cancel all plant dynamics, including the input/output delay that is present in all real plants. The only thing that can cancel a delay is a prediction, which AIC tries to do by forming an approximation to a predictive, *noncausal* compensator, i.e., a filter that produces an output before an input occurs. Of course this is impossible, and large control tracking errors result.

Much better results obtain if, rather than calling for perfect, delay-free tracking between command and response, the specification is relaxed a bit to say that some delay is acceptable. In other words, the desired model should be a simple delay. This delay is called *causality delay* because it allows AIC to create a causal compensator. The term *anticipation delay* is also used. The amount of anticipation delay should be at least as much as the input/output delay of the plant.

AIC can be extended to handle multichannel cross-coupled plants as shown in the 2-input/2-output system below:

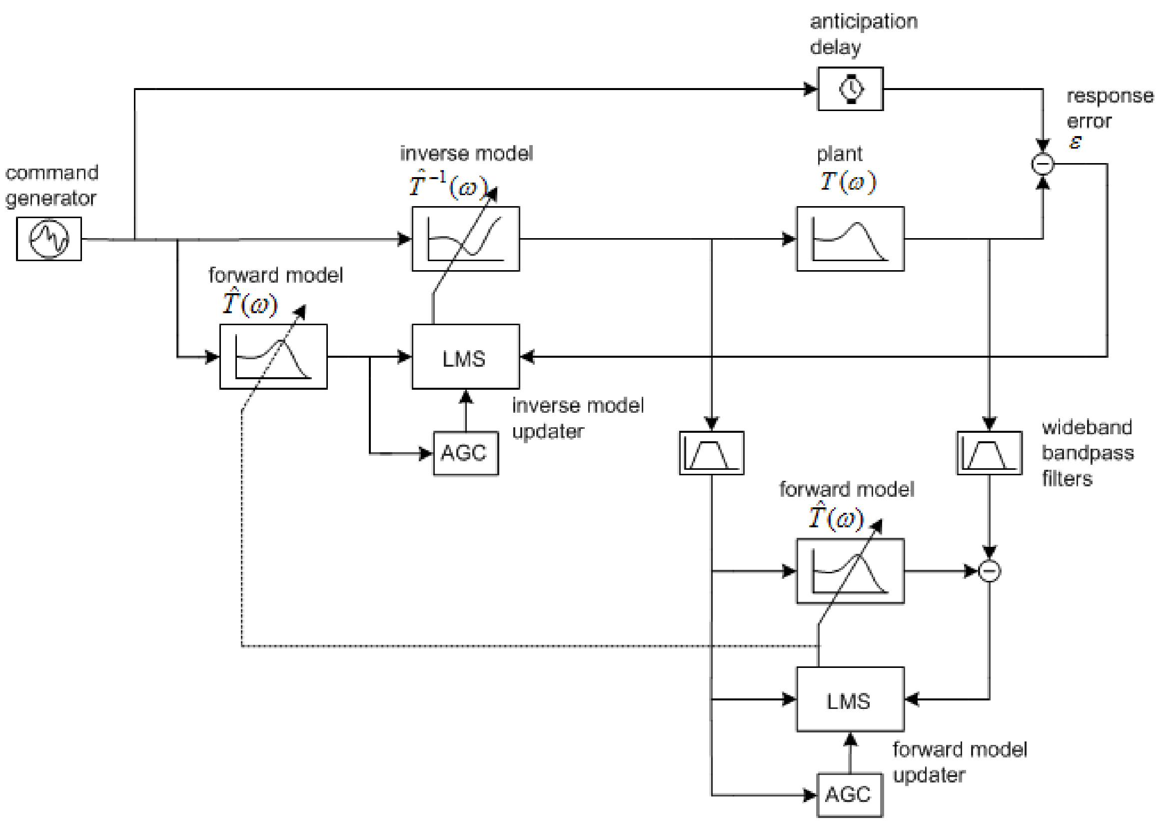


Instead of a single transfer function $T(\omega)$, the plant now consists of a matrix of transfer functions that represent the interaction between every combination of input and output. Likewise, AIC has a matrix of inverse models. The diagonal terms of the matrix correspond to the main interaction between each input and output; the off-diagonal terms correspond to undesirable cross-coupling interactions between channels. When AIC is perfectly adjusted, the matrix product of the inverse models with the plant models yield a matrix of transfer functions

$$\begin{bmatrix} D(\omega) & 0 \\ 0 & D(\omega) \end{bmatrix}$$

corresponding to perfect response of individual channels and no cross-coupling between channels.

A more detailed view of the internal structure of AIC (in the single-channel case) is shown below:



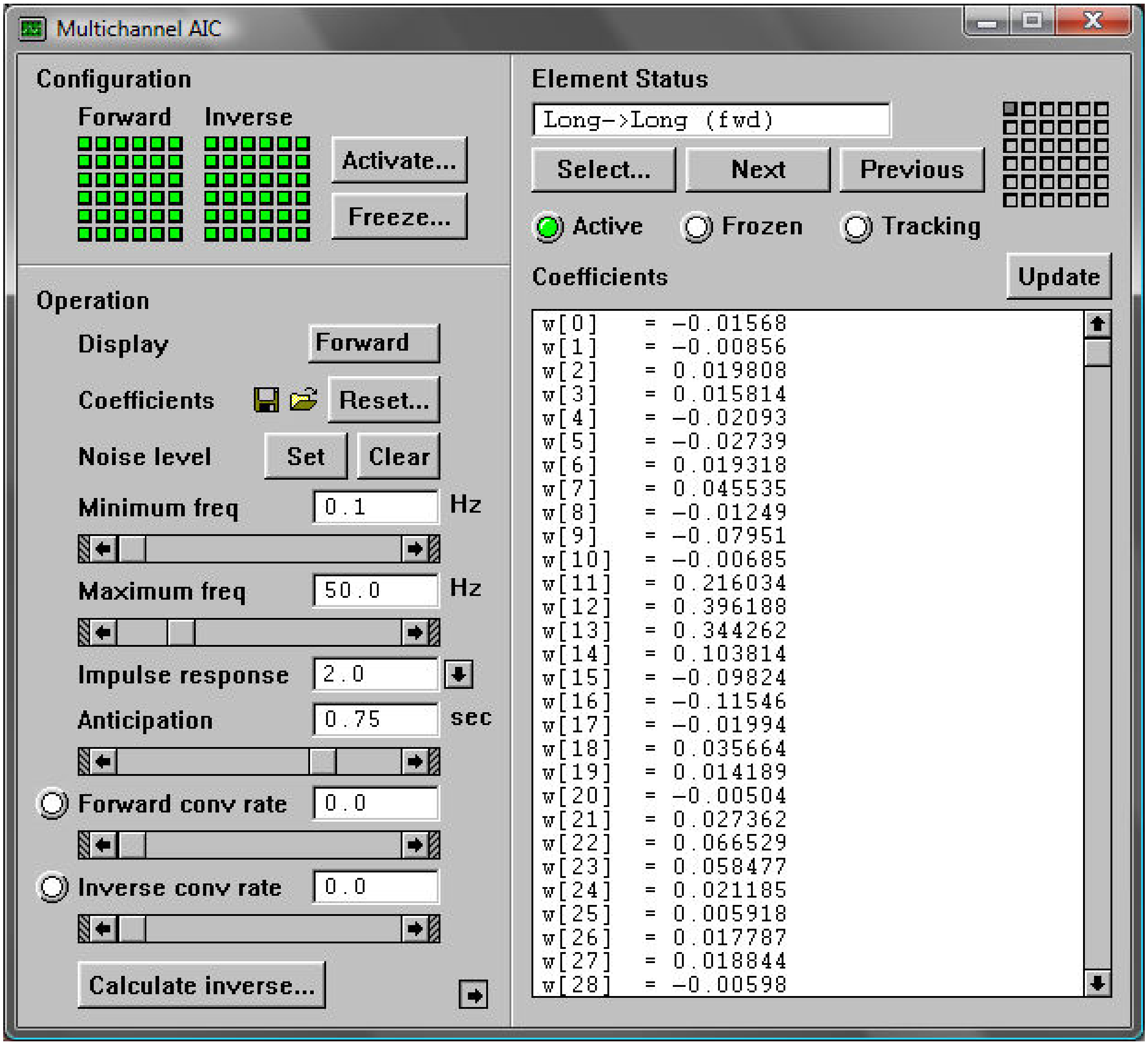
Note that the mechanism to estimate the inverse model requires knowledge of the forward model. So AIC requires that not only the inverse transfer function be measured online, but the forward transfer function as well. Both models are implemented as adaptive Finite Impulse Response (FIR) digital filters whose coefficients are modified using the Least Mean Square (LMS) algorithm. It is beyond the scope of this document to discuss specifics about adaptive filters; there are many good digital signal processing textbooks available on this topic.

We now turn to specifics on using AIC. After a description of AIC's user interface, a step-by-step operating procedure will be presented. For illustration purposes we shall use an example of a six degree-of-freedom seismic table control system with control channels named Long (X), Lat (Y), Vert (Z), Roll, Pitch, and Yaw.

In addition to AIC's user interface panel, you will be using other panels, namely:

- Main Panel
- Function Generator Panel
- Spectrum Analyzer Panel
- Frequency Response Function (IRF) Plotter
- Impulse Response Function (IRF) Plotter
- Digital Oscilloscope

AIC Panel Adjustments

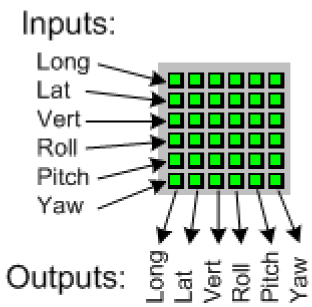


Configuration grid displays

Displays the activation status of a transfer function matrix element by color:

Green:	The element is active and its coefficients are enabled for adaption.
Yellow:	The element is active but its coefficients are frozen (adaptation is disabled).
Gray:	The element is inactive (pruned out of the matrix).

The location of an element within the grid is a function of the physical interaction that the element represents. System inputs are represented by rows and system outputs by columns, as shown below:

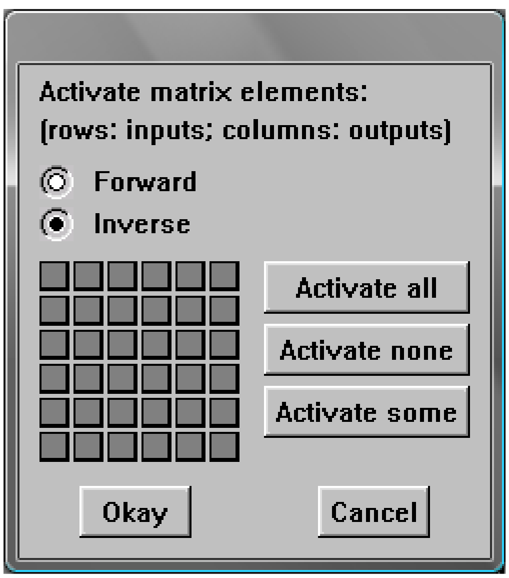


For example, the element in the sixth column of the second row is the element that represents the effect that Lat has on Yaw. This row-column interpretation applies to all grid indicators in this and other panels.

Activate button

Select transfer function matrix elements for activation or deactivation, as discussed in a later section "Pruning the Transfer Function Matrix".

Pressing the button causes this dialog to appear:



After selecting the matrix (forward or inverse) radio buttons, individual elements can be selected or deselected by touching elements of the square grid with the mouse. By clicking and holding the mouse down while sweeping the mouse, multiple elements can be selected or deselected at a time.

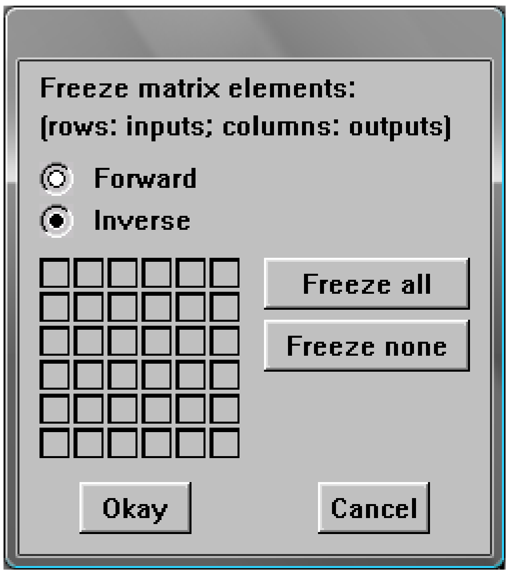
All elements can be selected or deselected at once by pressing the Activate All or Activate None button, respectively. When the Inverse matrix is selected, the Activate Some button becomes active. Pressing this button will select only those elements that need be active in order to achieve a proper inverse, depending on which forward matrix elements are active.

Selections and deselections do not take effect until the Okay button is pressed.

Freeze button

Select transfer function matrix elements for freezing or tracking.

Pressing the button causes this dialog to appear:



After selecting the matrix (forward or inverse) radio buttons, individual elements can be selected or deselected by touching elements of the square grid with the mouse. By clicking and holding the mouse down while sweeping the mouse, multiple elements can be selected or deselected at a time.

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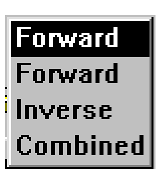
Display popup menu



Specify which transfer function matrix, forward, inverse, or combined forward-inverse, is the focus of various controls and displays, namely:

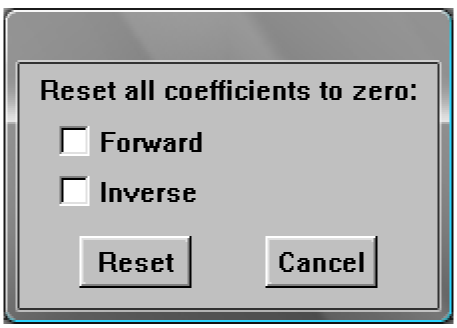
- Element Status list selector
- Element Status grid selector
- Frequency Response Function (FRF) Plotter grid selectors
- Impulse Response Function (IRF) Plotter grid selectors

Save Coefficients to File  and Restore Coefficients from File  buttons

Save and restore coefficient values to and from a text file. This is useful for backing up intermediate training results in case something goes wrong.

Reset All Coefficients button

Reset the coefficients of all elements of a transfer function matrix to zero. Before resetting, the dialog box shown below is displayed to allow you to designate whether coefficients in the forward or inverse or both transfer function matrices are reset.



Noise Level Set and Clear buttons

Set or clear the feedback noise threshold level that AIC uses to determine when the system is at rest so it can inhibit coefficient adaptation.

Minimum and Maximum Frequency slider bars

Set the frequency range in which AIC concentrates its effort. Signal energy outside this frequency range is discounted as noise. This is done by filtering the signals input to AIC with bandpass filters whose cut-in and cutoff frequencies are the minimum and maximum frequencies, respectively. When the Calculate Inverse button is used to compute the system inverse, frequency bins outside this frequency range are actually zeroed.

Impulse Response popup menu

Set the impulse response length of all AIC filter elements. Selecting of the proper impulse response length is discussed in detail in a later section.

Anticipation slider bar

Set the anticipation delay that allows AIC to create a causal compensator. Selecting the anticipation delay is discussed in detail in a later section.

Forward & Inverse Convergence Rate slider bars

Set the convergence rate of the coefficient adaptation process. A value of zero means no adaptation; higher values increase the speed of the adaptation process at a cost of decreased transfer function accuracy. Too high of a value will cause the adaptation process to diverge, driving the coefficients to infinity. A convergence rate of less than one is usually (but not necessarily) safe.

Forward & Inverse Tracking indicators 

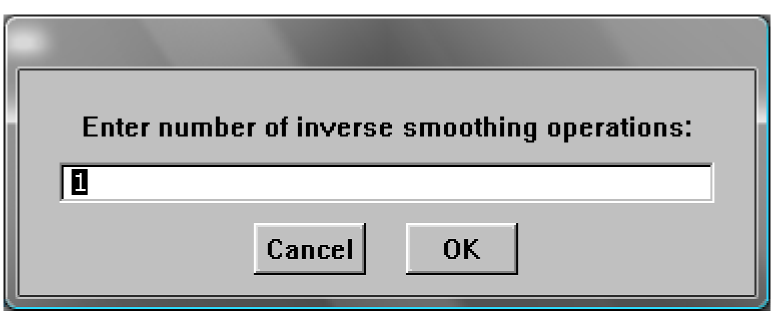
Displays the current state of the coefficient adaptation process. The tracking indicator is green if any active transfer function element is adapting. If no transfer function elements are adapting, the indicator is white. The conditions for tracking are:

- The AIC mode is set to Training or Tracking.
- The convergence rate is nonzero.
- The master span is nonzero (i.e., the Run button on the Main Panel has been pressed). Note that the local span (i.e., the Run button on the Function Generator Panel) has no effect on tracking.
- The feedback signal level is above the noise threshold level determined by pressing Noise Level Set button.

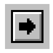
Calculate Inverse button

Calculate the inverse transfer function matrix instantly rather than adapting incrementally over time.

Pressing the button causes this dialog to appear:



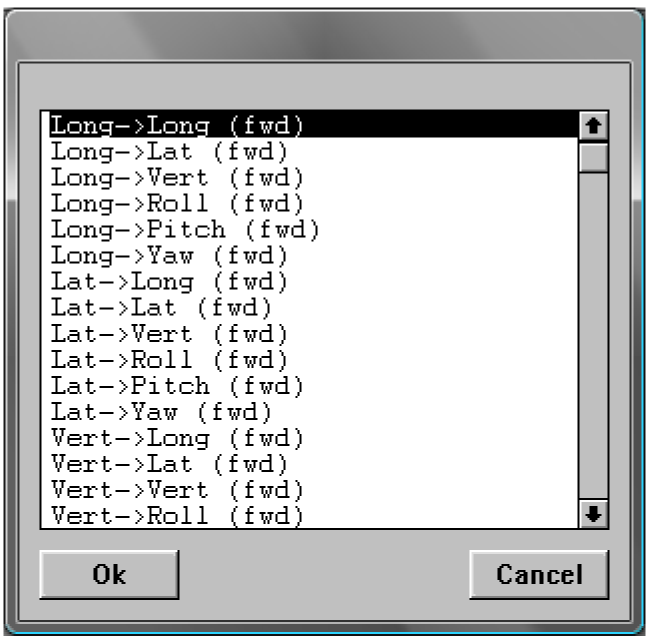
Enter the number of times the smoothing window will be applied to the system inverse. Smoothing will reduce Gibbs oscillation in the inverse that occurs when frequency bins are zeroed according to the frequency range specified by the minimum and maximum frequency slider bars. A value of zero is a legal input value corresponding to no smoothing.

Expand Window button 

Expand the panel so that the right half pane of the AIC window is visible. The right half pane contains various controls and displaces that allow an individual transfer function matrix element to be examined or manipulated.

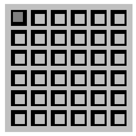
Element Status list selector 

Select an individual transfer function matrix element for examination or manipulation.



The Select button calls up a dialog with all elements presented in a linear list from which a single element can be selected. Next and Previous buttons cycle through the list without having to call up the element selection dialog.

The Display popup menu determines which transfer function matrix elements are listed: forward, inverse inverse, or combined forward-inverse.

Element Status grid selector 

Select individual transfer function matrix elements for manipulation or examination by clicking on box corresponding to the desired element. This provides a convenient alternative to the Element Status list selector as a means of selecting an element.

The Display popup menu determines which transfer function matrix elements are listed: forward, inverse inverse, or combined forward-inverse.

Note that Element Status grid selector looks superficially similar to the Configuration grid displays. However, their purpose and operation are quite different. The former is an graphical control used for selecting a particular element, whereas the latter is a graphical display that shows the activation status of all elements.

Element Active/Frozen/Tracking status indicators 

The Active indicator shows whether a particular element within a transfer function matrix has been activated or deactivated.

The Frozen indicators shows whether an element is active but its coefficients frozen (adaptation disabled).

The Tracking indicator is similar to the Forward and Inverse Tracking Indicators described above, except that it displays the tracking status of a particular transfer function matrix element rather than all elements.

Coefficients Update button

Update the Coefficients text display with current values of the coefficients of a particular transfer function matrix element.

Coefficients text display

Displays textually the current values of the coefficients of a particular transfer function matrix element. This information is also displayed graphically in the Impulse Response Function (IRF) Plotter.

AIC Operating Modes

AIC has four operating modes available from a popup menu on the Main Panel:

These modes are:

Disabled: AIC is off.

Frozen: AIC is on and controlling, but coefficients are unchanging This is the mode recommended for running most tests.

Tracking: AIC is on and controlling, and coefficients are changing. This mode is used to refine coefficients during training, as well as adapting to changing plant dynamics during a test.

Training: AIC is on but not controlling. Plant input and output are passively monitored while coefficients are updated. This mode is used to determine initial values of transfer function coefficients prior to running Frozen or Tracking modes.

Sequence of Operation

The typical sequence of operation of AIC is as follows:

1) In Training mode, train the forward transfer functions.
2) In Training mode, train the inverse transfer functions.
3) Switch to Frozen or Tracking mode and run the test.

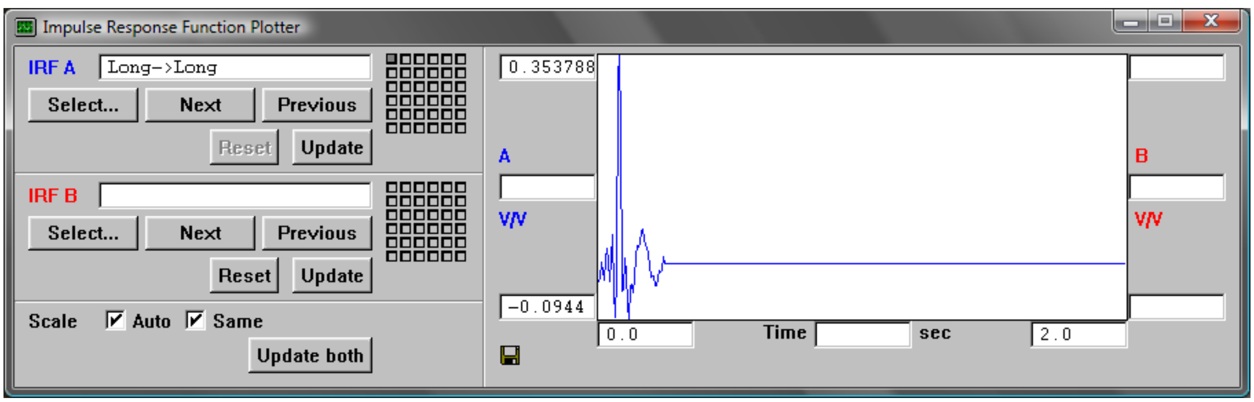
Each step of the operating sequence will be described in detail in later sections. However, before operating AIC, you must first select the values of two key parameters: impulse response length, and anticipation delay. The impulse response is the amount of time that AIC has to influence the response of the system. The anticipation delay is amount of time AIC has to prepare the system for a significant motion event. The following section provides guidance on selecting these parameters.

Selecting the Impulse Response Length and Anticipation Delay

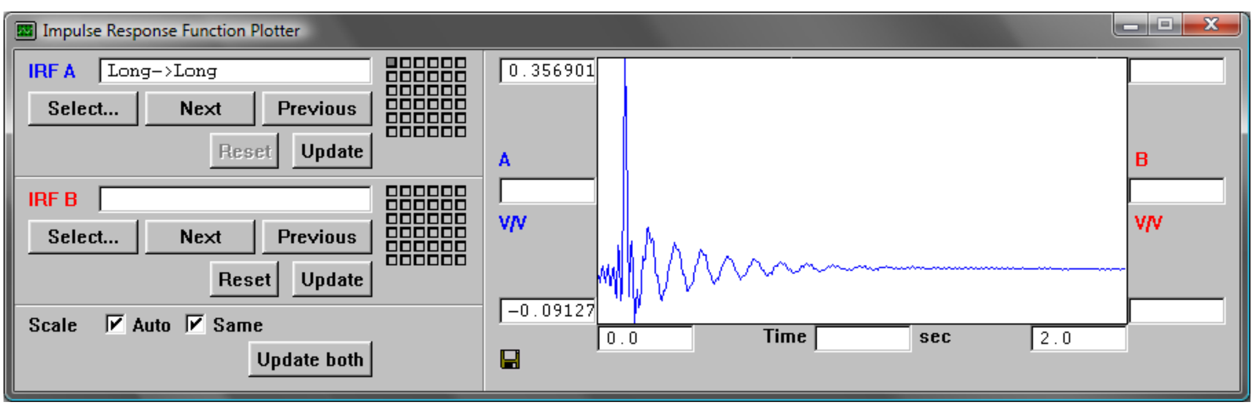
Choosing the optimum amount of impulse response length and anticipation delay is important: too little results in decreased control accuracy; too much results in slower convergence. There is no simple rule for determining the impulse response length. The basic rule for choosing the amount of anticipation delay is that it must be at least as much as the input/output delay of the plant, but how much more is optimum is not easy to determine. So finding optimum values for these quantities is best done by trial and error, as follows:

First, choose a long impulse response length and train the forward transfer functions using the Training procedure described in later sections. Using the Impulse Response Function (IRF) Plotter, verify that the inverse impulse responses are not too short. A perfectly captured impulse response begins at zero, grows in amplitude, then decays back to zero, without having large intervals of zero amplitude on either side of the main pulse.

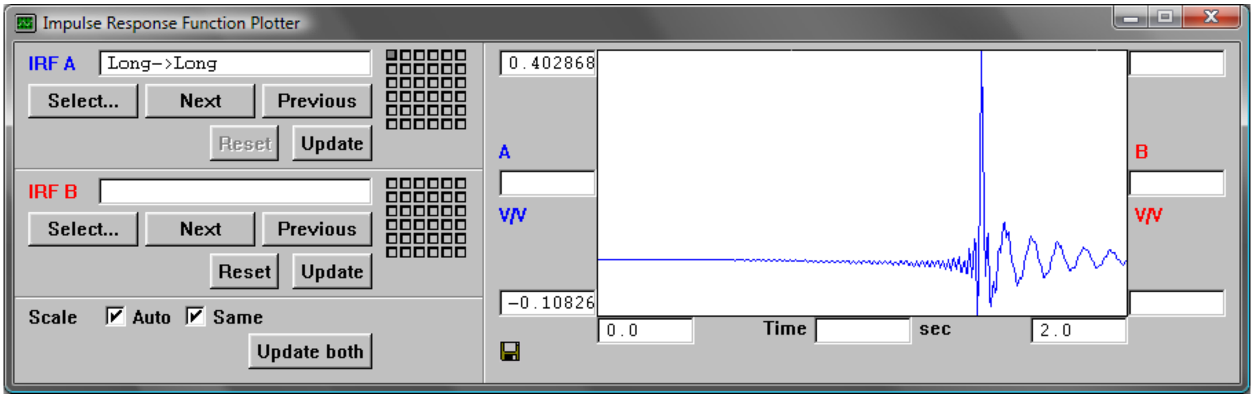
An example of a too-short impulse response is:



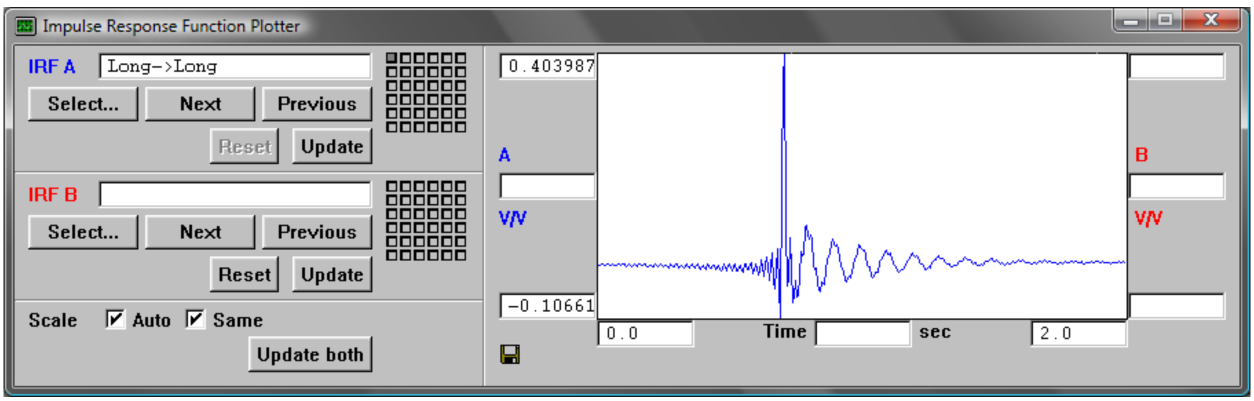
Increase the impulse response length allow the ringing tail end to decay to zero:



The impulse response now has sufficient length, but has a truncated front end, so the anticipation delay should be increased to shift the impulse to the right (the anticipation delay determines the approximate location of the main pulse within the impulse response interval):



The impulse response now has too many zeros on the front end and truncated tail end, so the anticipation delay should be reduced to shift the impulse to the left:



This impulse reponse is just right: it is centered so that it begins and ends near zero.

When searching for optimum values of impulse response length and anticipation delay, keep in mind these helpful tips:

- The impulse response can be changed without having to retrain the forward transfer function, provided that it is not made so short as to truncate forward impulse response.
- Use the Calculate Inverse button to recompute the inverse after changing the impulse response length or anticipation delay.
- It is better to have too impulse response length and anticipation delay rather than too little. Too much only slows down convergence a bit; too little causes control accuracy to quickly degrade.

Training the Forward Transfer Functions

Step 1: *Prune the forward transfer function matrix (optional)*. As discussed in a later section.

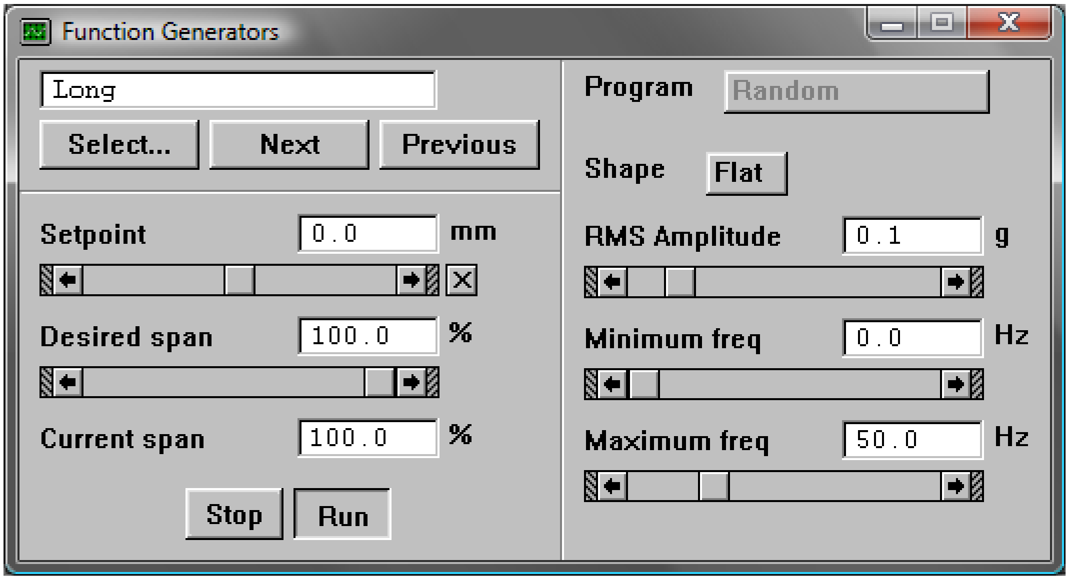
Step 2: *Set up the random function generators*. For all active channels, set up each random function generator identically. Each random function generator consists of a uniform distribution random number generator followed by a bandpass filter. This filter has four parameters that you must enter (see figure below):

Maximum frequency: This is the cutoff frequency of the bandpass filter. Set this according to the highest frequency expected in your test waveform. Also enter this maximum frequency into the Maximum Frequency slider bar in the AIC Panel. This allows AIC to ignore higher frequencies, resulting in more accurate control in the frequency band of interest.

Minimum frequency: This is the cut-in frequency of the bandpass filter. Set this according to the lowest frequency expected in your test waveform. A minimum frequency of zero is allowed. In seismic controllers in acceleration control mode, this frequency should match the cut-in frequency of the Reference Generator. Also enter this minimum frequency into the Minimum Frequency slider bar in the AIC Panel. This allows AIC to ignore lower frequencies, resulting in more accurate control in the frequency band of interest.

RMS amplitude: Adjust the RMS amplitude to the minimum value possible to prevent damage to the test specimen. Keep in mind, however, that using too low of an amplitude that is within the noise and friction levels of the system will result in inaccurate transfer function estimates. If your system is significantly nonlinear, try to use an RMS amplitude similar in amplitude to the test waveform if possible, because in such systems the transfer function is a strong function of signal amplitude. Also, keep in mind that you are setting RMS amplitude, not peak amplitude; peak amplitude will be higher than RMS amplitude.

Shape: This is the shape of the bandpass filter's magnitude response as a function of frequency between minimum and maximum frequencies. Five shapes are available: 1/F^2, 1/F, Flat, F, and F^2, where "F" denotes frequency. The primary consideration in selecting the shape is to get the most energy into the system across the frequency band of interest without damaging the system by excessive velocity or acceleration. In acceleration control systems, "Flat" works well, but in displacement control systems, "Flat" will result in excessive velocity and acceleration at high frequencies; "1/F" or "1/F^2" is much gentler on the system in that case. Shapes "F" and "F^2" accentuate acceleration at high frequencies and so should not be used. Note that theoretically a shape of "1/F" or "1/F^2" results in a filter magnitude response that tends toward infinity as the frequency tends toward zero. This is neither desirable nor practical, so the filter response is rolled off to zero as the frequency approaches the minimum frequency. In addition, for technical reasons the minimum frequency is not allowed to be less than certain small fraction of the maximum frequency or the controller sample frequency when “1/F” and “1/F^2” shapes are selected.



Step 3: *Turn on AIC in Training mode from the Main Panel.*

In Training mode, AIC is on but is not controlling. Instead, it passively monitors command and feedback to the system and updates its transfer function estimates accordingly.

Step 4: *Set the noise level (optional).* After waiting at least two impulse response intervals after turning on AIC, press the Noise Level Set button. This causes AIC to measure its feedback noise level to determine the response threshold below which it will inhibit adaptation. This prevents AIC from adapting to noise when the system is at rest, which can quickly cause the coefficients to become large or infinite in magnitude.

You may have to set the noise level other times as well if you change a controller setting that affects the filtering experienced by system feedbacks. Such settings are:

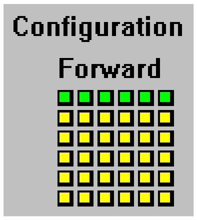
- AIC minimum and maximum frequency.
- Feedback conditioner filter bandwidth.
- Any controller gain setting.

When setting the noise level, make sure that AIC is on with the convergence rates set to zero and that the system is at rest for a period of time at least as long as twice the impulse response length. If you make the common mistake of setting the noise level when the system is in motion, set it to back to zero by pressing the Noise Level Clear button and redo this step once the system is at rest.

You can opt not to use this feature if you are content to let the controller enable and disable adaptation based on the master span (i.e., the Run and Stop buttons on the Main

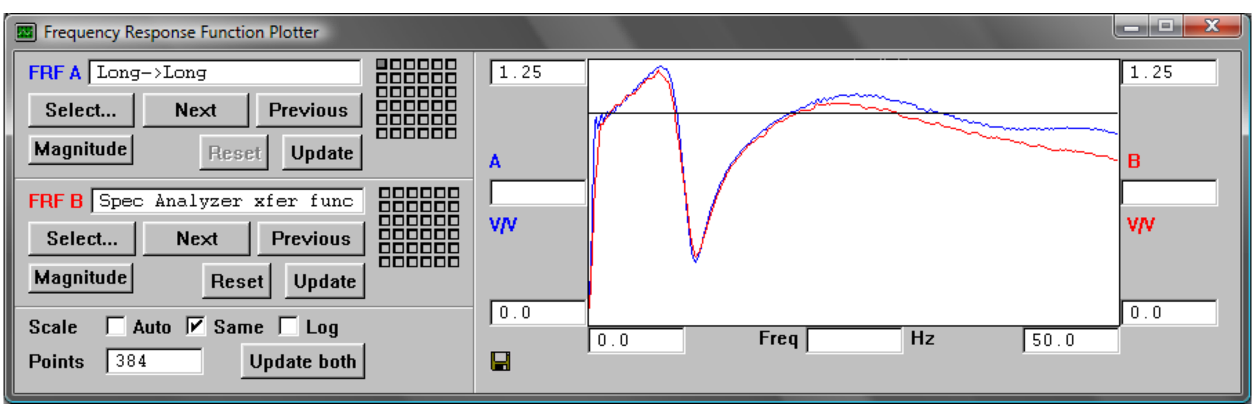
Panel), or if you set and clear the convergence rate manually. This feature simply adds an additional layer of protection to the existing mechanism.

Step 5: *Train the first active row of transfer function elements*. First, unfreeze all elements in this row and freeze all elements in other rows. For example, when all elements in the Long row are unfrozen and those of all other rows are frozen, the forward Configuration grid display looks like this:



Next, make sure that the function generators of all other rows are in a stopped state. Then start the function generator by pressing the Run button. After motion has begun, move the Forward Convergence Rate slider bar away from zero. The coefficients of elements in the training row will begin to change. This can be observed textually in the coefficient display of the AIC Panel, and graphically in the FRF and IRF Plotters. Another indication of coefficient adaptation is the green color of the tracking indicator next to the Forward Convergence Rate slider bar.

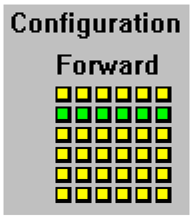
While training is in progress, it is a good idea to verify that it is proceeding correctly by comparing the transfer functions estimated by AIC with those estimated independently by the Spectrum Analyzer. For example, Channel A (blue) of the FRF Plotter shown below shows the Long->Long forward transfer function identified by AIC; Channel B (red) shows the same transfer function identified by the Spectrum Analyzer. Note that they are similar, but not the same (especially the phase responses, not shown) because embedded in the AIC transfer function are effects of filters internal to AIC that the Spectrum Analyzer cannot see.



After the transfer function has substantially converged, it is time to begin a process known as "coefficient polishing". Slowly reduce the convergence rate in stages, waiting a while between stages to allow time for the coefficients to approach their optimum values. Visually, the transfer functions will become much more smooth.

Finally, after reducing the convergence rate to zero, stop the function generator by pressing the Stop button. If you forget to zero the convergence rate, pressing the Stop button in Training mode will automatically do it for you.

Step 6: *Train subsequent active rows of transfer function elements*. Repeat the previous step for all other active rows. For example, when all elements in the Lat row are unfrozen and those of all other rows are frozen, the forward Configuration grid display looks like this:



When training the forward transfer functions, you may want to occasionally back up the coefficients to a coefficient file using the  button. That way if you accidentally reset or modify the coefficients of elements already trained, you can easily recover them using the  button.

When all active rows of the forward transfer function matrix have been trained, it is time to train the inverse transfer function matrix.

Training the Inverse Transfer Functions

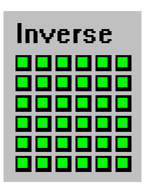
There are two ways to train the inverse transfer functions. The first way, which is by far the most convenient and preferred way, is simply to press the Calculate Inverse button. The second way, described below, is to use adaptation, which is much less convenient because it takes time. At one time, before the Calculate Inverse feature was added to AIC, adaptation was the only way to train the inverse transfer functions. The adaptation method, which has been retained for legacy reasons, is described in the section below. You may skip this section.

Training the inverse transfer functions using adaptation can be done with hydraulics off because AIC uses only internal forward model feedbacks rather than actual system feedbacks to train the inverse. This is convenient because your specimen will receive less cumulative damage if the length of time that the specimen is actually shaken is limited to the length of time it takes to train the forward transfer functions. Of course you can still opt to train the inverse with hydraulics on, in which case you will not have to cycle hydraulic power.

Step 1: *Complete the training of the forward transfer functions*. The inverse transfer functions will not converge unless all forward transfer functions are reasonably accurate.

Step 2: *Prune the inverse transfer function matrix (optional)*. As discussed in a later section.

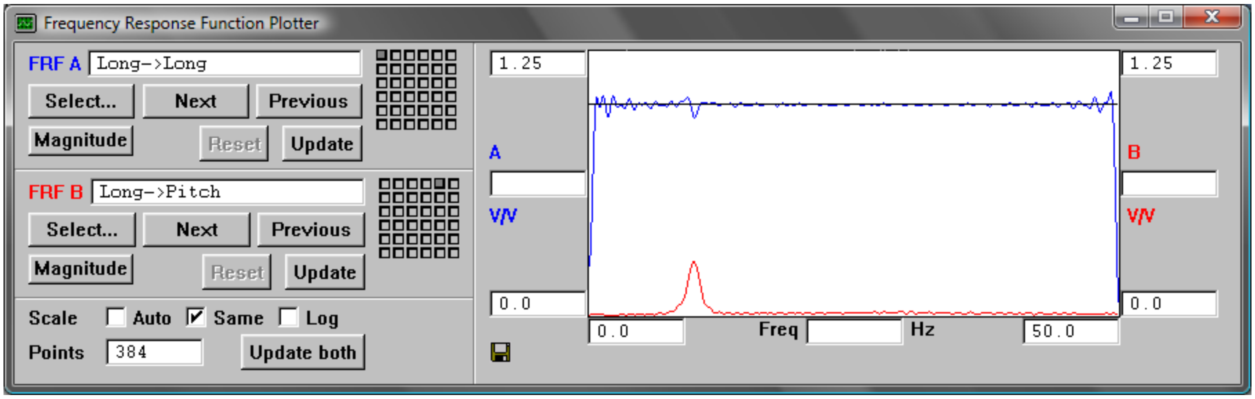
Step 3: *Train all active transfer function elements*. Unlike the forward transfer function matrix, which can be trained row by row, all active elements of the inverse transfer function matrix should be trained simultaneously. (Although it is possible to train column by column, there is no advantage in doing so.) First, unfreeze all elements in the inverse transfer function matrix. For example, the inverse Configuration grid display should look like this:



Next, make sure that all function generators corresponding to active rows of the *forward* transfer function matrix are in a running state. You can use the same random function generator setup that you used to train the forward transfer functions. Then start the function generators by pressing the Run button. After motion has begun, move the Inverse Convergence Rate slider bar away from zero. The coefficients of active elements will begin to change. This can be observed textually in the coefficient display of the AIC Panel, and graphically in the FRF and IRF Plotters. Another indication of coefficient adaptation is the green color of the tracking indicator next to the Inverse Convergence Rate slider bar.

If you find that you need a different anticipation delay, you can change it without having to retrain the forward transfer functions. After making such a change, resetting the inverse transfer functions to zero will reduce the retraining time.

While training is in progress, it is a good idea to verify that it is proceeding correctly by looking at the combined forward-inverse transfer functions using the FRF Plotter. For example, Channel A (blue) of the FRF Plotter shown below shows the Long->Long combined forward-inverse, which is ideally unity for all frequencies, and Channel B (red) shows Long->Pitch combined forward-inverse, which is ideally zero for all frequencies. These are typical of on- and off-diagonal combined forward-inverse FRFs.



Once training is complete, it is a good idea to look at the inverse FRFs. An inverse that is large in magnitude or is noisy-looking may be an indication of a problem. Typical on-diagonal inverses vary around unity (shown as a black line in the FRF Plotter. However, it is difficult to determine what "large" is for off-diagonal inverses because their magnitudes are affected by differences in engineering units between input and output. Guidelines on how to interpret the relative size of off-diagonal transfer functions are discussed in a later section, “Pruning the Transfer Function Matrix”.

Usually bad inverse transfer functions are due to inadequately trained forward transfer functions. You may need to go back and retrain or refine the forward transfer functions. Then reset the inverses to zero and start over.

When the coefficients have converged, polish them by gradually reducing the convergence rate as described previously.

Training is now complete, so you can proceed to running your test. At this point is a good idea to save AIC setup and transfer function coefficient values to a settings file using the Main Panel's File, Save Settings menu item.

Running the Test in Frozen Mode

In Frozen mode, AIC actively controls the plant, but the transfer functions it uses are fixed (hence the name "frozen" for this mode) and do not adapt. This is the safest mode of operation, because the potential for instability does not exist.

When you run a test, switch AIC to Frozen mode using the popup menu on the Main Panel. Before doing so, remember to examine all active inverse transfer functions using the FRF Plotter to verify that they look reasonable. A bad inverse can cause violent motion that can damage or destroy your specimen and your test machine.

Keep in mind that AIC has a large input/output delay equal to twice the impulse response length due to internal data framing, plus anticipation delay. This means that when you press the Run button on the Main Panel to run your test, you won't see any motion for at least 8 seconds if your impulse response length is 4 seconds (for example). Likewise, motion will continue for up to 8 seconds after you press the Stop button. Be patient.

Running the Test in Tracking Mode

In Tracking mode, not only does AIC actively controls the plant, but also it updates the transfer functions it uses based on its estimate of plant dynamics. Therefore it is capable of tracking changes in plant dynamics (hence the name "tracking" for this mode). Because the transfer functions vary according to plant feedback, the potential for instability exists that can instantly destroy your specimen and damage your test machine. For this reason, it is strongly recommended that you do not use this mode unless

1) You are thoroughly familiar with operating AIC in Frozen mode.
2) You have determined that Tracking mode is appropriate for your test, and
3) You have contacted MTS technical support for assistance.

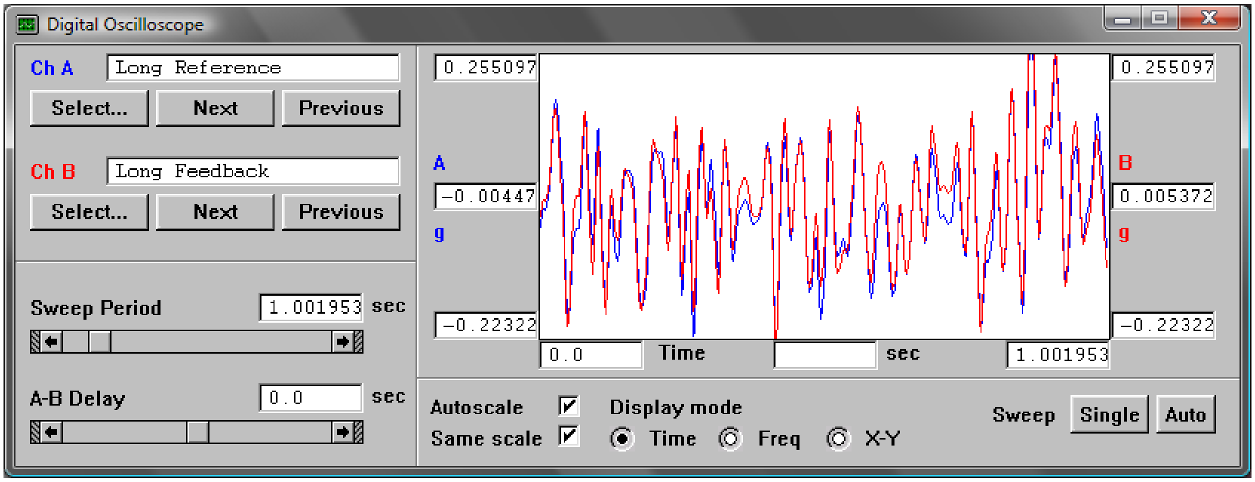
The decision of whether Tracking mode is appropriate for your test depends on the duration of the test and whether or not you expect plant dynamics to change significantly during the test. If you expect the dynamics to change significantly *and* the test duration is long enough for AIC to adapt to those changes, then Tracking is the mode to use. Due to internal delay, AIC won't respond to changing dynamics for a period of time up to twice the impulse response length. For an impulse response four seconds long, this means that the adaptation latency is eight seconds long. If your test is less than eight seconds in duration, Tracking mode will not be useful.

If you decide to use Tracking mode, your command waveform must have a broad enough bandwidth to excite all dynamic modes of the plant within the frequency range that you specified in the AIC Panel. In other words, it is not a good idea to use narrowband or periodic commands when AIC is in Tracking mode. If the command contains only a limited number of frequencies, AIC will adapt only at those frequencies while gradually forgetting what it has learned at all other frequencies. Even so, you will get good matching response for that particular command waveform, but if you then change the command's frequency content, large control errors will suddenly arise while AIC tries to relearn what it has forgotten.

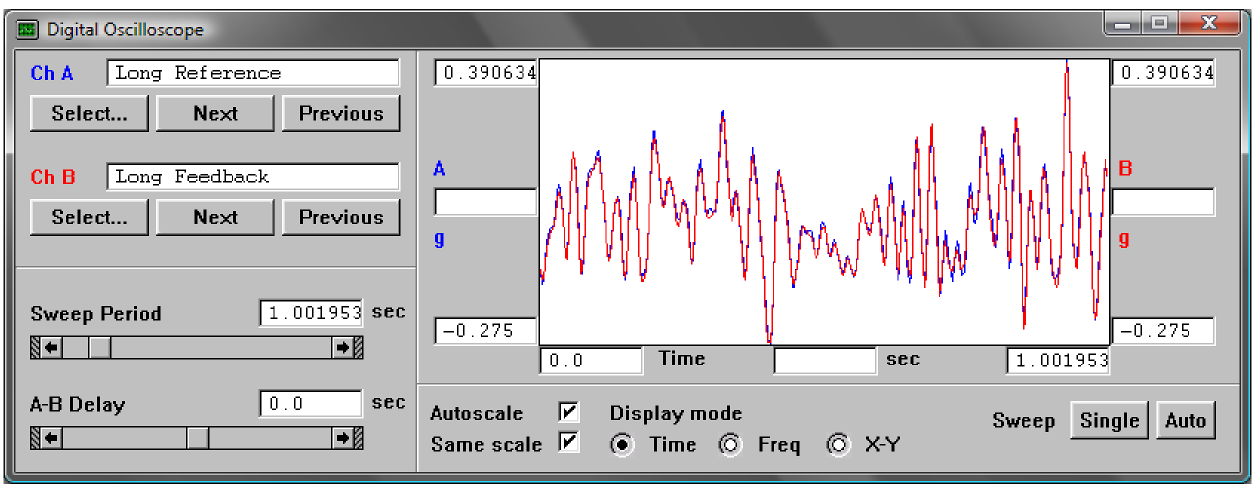
Viewing the Results

You can use the Digital Oscilloscope to monitor command and response time waveforms, or the Spectrum Analyzer and the FRF Plotter to observe forward, inverse, and combined forward-inverse transfer functions.

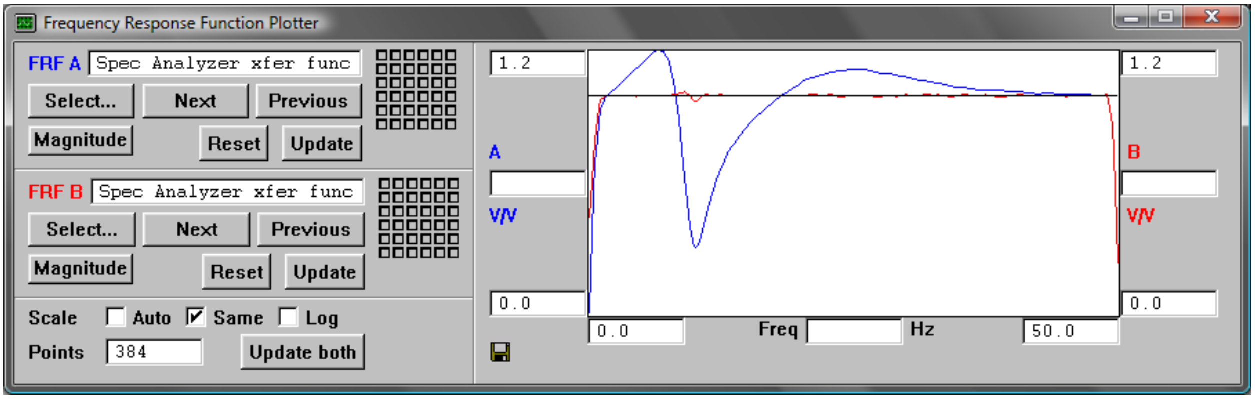
Below is an example showing Long command and response without AIC:



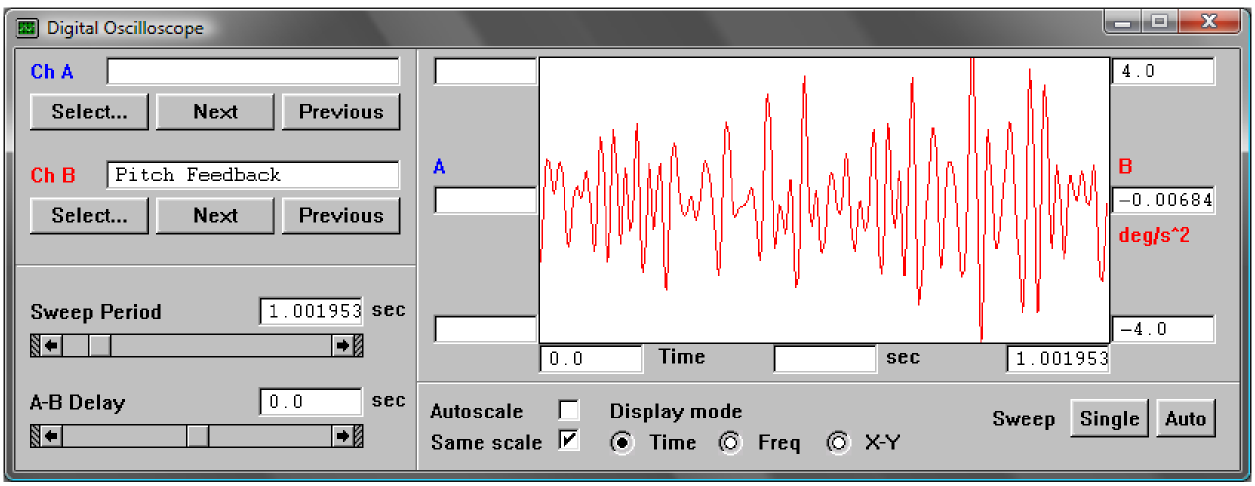
With AIC, Long command and response are almost perfectly overlaid:



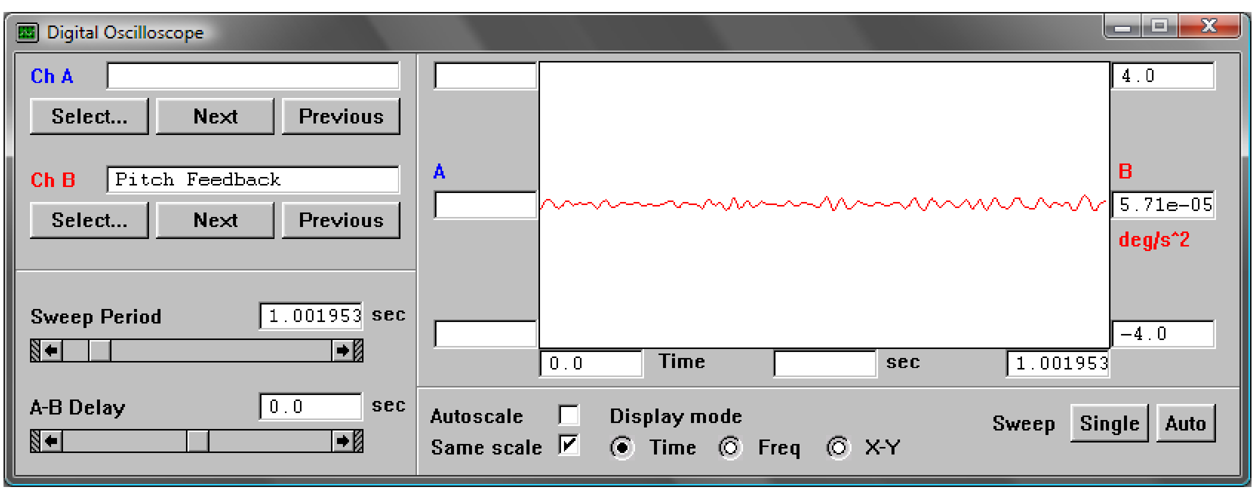
Long->Long frequency response with AIC (Channel B (red)) shows a substantial improvement over that without AIC (Channel A (blue)) and is almost perfectly unity at most frequencies:



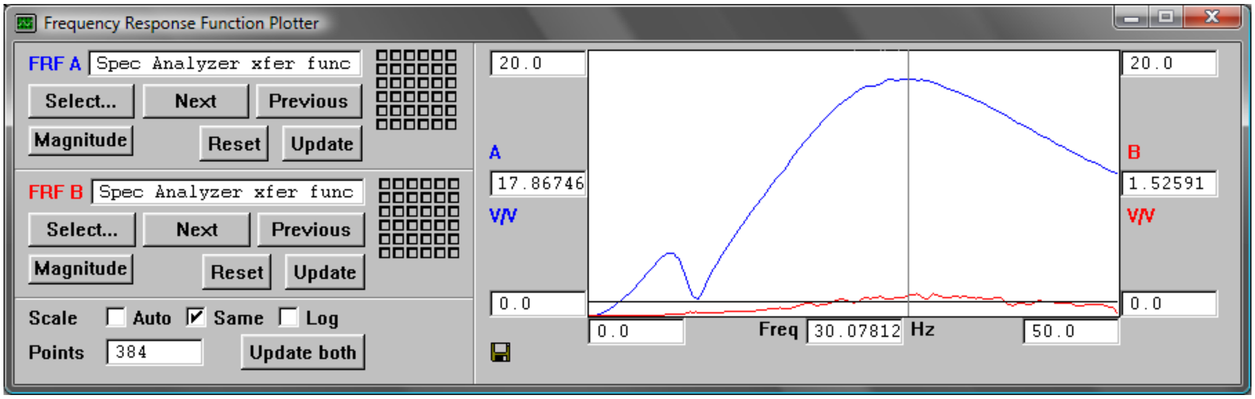
Below shows the cross-coupling on Pitch due to Long without AIC:



With AIC, the cross-coupling on Pitch due to Long is greatly reduced:



The cross-coupling on Pitch due to Long (Channel B (red)) shows a factor of ten reduction over that without AIC (Channel A (blue)):



Advanced Topic: Pruning the Transfer Function Matrix

AIC has the capability to measure the transfer function between all combinations of input and output. However, in real systems it is not the case that every channel is physically coupled to every other channel. When cross-coupling is weak or nonexistent, removing those elements from the transfer function matrix will speed convergence and improve transfer function accuracy. The process of determining which off-diagonal elements are negligible and then removing those terms is called "pruning".

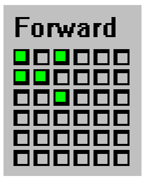
Although pruning can be beneficial, doing it incorrectly can have detrimental effects that far outweigh the potential benefit. So if you have any doubt about whether or not to prune an element, keep it in the matrix.

To determine which elements can be pruned, excite a single channel and measure the transfer functions between the command and off-diagonal feedbacks with the Spectrum Analyzer. If the resultant off-diagonal transfer function is “small”, prune out the corresponding forward transfer function matrix element by de-selecting its grid element in the Activate Matrix Elements dialog.

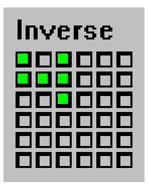
Determining what is a “small” transfer function depends its location in the matrix. For on-diagonal elements, “small” means significantly smaller than unity. The same is true for off-diagonal elements representing translation-to-translational or rotation-to-rotational cross-coupling. However, for off-diagonal elements representing translation-to-rotational or rotational-to-translational cross-coupling, magnitudes are affected by differences in engineering units between input and output, making it difficult by simple inspection to assess what is “small”. In these cases it is necessary to normalize the magnitude of the transfer function to a fraction of fullscale by multiplying it by *fullscale input units / fullscale output units*. If normalized transfer function is significantly less than unity, then it is considered to be “small”.

When pruning the forward transfer function matrix, keep in mind that if any element in a row is active, then the diagonal element for that row must be active.

Once the forward transfer function matrix has been pruned, the next step is to prune the inverse transfer function matrix. The pruning of the inverse matrix is totally determined by the pruning of the forward matrix, but it is not always obvious which elements of the inverse matrix will be nonzero, given nonzero elements of the forward matrix. For example, the appropriate inverse pruning of the forward matrix



happens to be



It is not obvious that element 2,3 of the inverse matrix must be nonzero. Because it is difficult to determine the proper pruning of the inverse matrix by inspection, let AIC ind it for you by using the Activate Some button in the Activate Matrix Elements dialog: