Real Time Hybrid Seismic Test System User's Manual

MTS®

State University of New York
at Buffalo (SUNY)
US1.17858.EQT

Copyright information

Contact information

MTS Systems Corporation
14000 Technology Drive
Eden Prairie, Minnesota 55344-2290 USA
Toll Free Phone: 800-328-2255 (within the U.S. or Canada)
Phone: 952-937-4000 (outside the U.S. or Canada)
Fax: 952-937-4515
E-mail: info@mts.com
http://www.mts.com

Publication information

Publication Date
Oct 2004

Table of Contents

Section 1 System Overview

Section 2 Operator's Safety Practices

Section 3 Understanding Control Principles

Section 4 Introduction to Control Software

Section 5 Control Panel Reference

Section 6 Operation

Section 7 Maintenance Procedures

Section 8 Calibration and Tuning

Section 9 Hydraulic Power Controller Reference

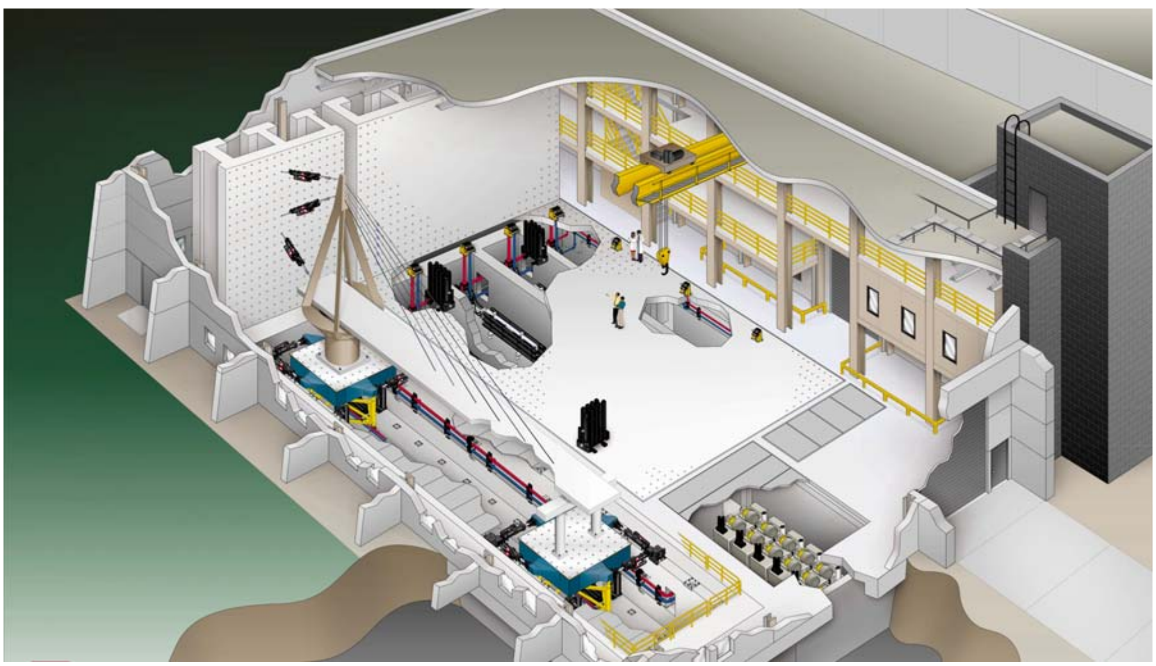
Appendix A Scramnet Signals and Paramaters

Section 1

Overview

This section of the User's Manual provides a brief description of the Seismic Test System designed by MTS Systems Corporation for the State University of New York at Buffalo (SUNY). It also identifies the model, quantity, and function of the major components used in this system.

The MTS seismic test system is designed to investigate the characteristics of table-mounted specimens undergoing simulated earthquakes generated from a program input. The SUNY test system has been specifically designed to allow the tables to be easily repositioned in the lab so that a wide variety of structure sizes can be tested on the system. The SUNY test system facility is illustrated below.



University of Buffalo (SUNY) System Facility

The SUNY Seismic test system contains the following hardware:

- 2 seismic tables support the specimen to be tested.
- Parking frames located under each table to support and lift the table.

- 4 horizontal and 4 vertical table actuators support each table and apply the force necessary to create the desired table movement during seismic testing.
- The hydraulic power supply system and hydraulic distribution system provide hydraulic power to the system actuator servovalves.
- The control system conditions, monitors, and generates program command and feedback signals for control of the test system.
- The digital system provides computerized program management through the conversion of program command signals from digital to analog forms and the conversion of feedback signals from analog to digital forms. It also provides data acquisition, processing, and storage functions for data acquired during testing.

All of these major system components are discussed in the following subsections. It is important to note that these descriptions are generic in nature. More detailed information about each component, including engineering drawings, is included in appropriate sections of the system Reference Manual.

The system operator should obtain a good functional understanding of all major system components before attempting to operate the system. Failure to do so could lead to serious safety problems.

Seismic Tables

The 2 seismic tables are constructed to provide high stiffness with minimum possible weight. The upper surface of the table contains threaded mounting holes for attaching specimens. Reinforced sections of the seismic table accommodate attachment of the hydraulic actuators.

Parking Frame

Under each table is a parking frame assembly that supports the table in a steady midstroke position during specimen loading. The parking frame also supports the table and actuators as the frame is rolled to a new location for different test requirements.

Parking Frame

Mechanical screw jacks, located in each corner of the parking frame, are used to support or lift the table assembly. The parking frames also include an integrated hydraulic service manifold and large accumulators for peak flow demands.

Hydraulic Actuators

The 4 vertical and 4 horizontal table actuators used in the seismic test system are specially designed, low-friction 244.40S hydraulic actuators. They are mounted to the seismic table and the foundation walls with swivel mounting fixtures.

Actuator operation is accomplished by porting high-pressure hydraulic fluid into the actuator cylinders through the servovalve. As fluid is ported into the cylinder, pressure is applied to one side of the piston, the other side is opened to the return line, and the resulting differential pressure causes the piston to move. If the piston rod is connected to some external reaction point, as in a seismic test system, a force is applied that is equal to the effective piston area times the differential pressure. As the actuator drives the table/specimen mass, inertial forces are developed in direct proportion to displacement and frequency.

A linear variable differential transformer (LVDT) is mounted inside each actuator to provide an electrical feedback signal that indicates the actuator piston rod position.

A pressure transducer measures the differential pressure (ΔP) on the piston. This feedback is used for control stability and rough force measurement.

Servovalves

The actuators are equipped with servovalves that control the direction and amount of fluid flow to the actuators.

For the seismic system, the following servovalves are used:

Horizontal actuators:

- 256.25S servovalve (main stage) = 1000 liter/min rating (264 gpm)
- 252.24G-01 pilot valve= 10 gpm rating

Vertical actuators:

- 256 servovalve (main stage) = 630 liter/min rating (166 gpm)
- 252.23G-01 pilot valve= 5 gpm rating

Rated flow is the flow through the valve with 1000 psi pressure differential across the ports.

When the servovalve slave stage spool is in the hydraulic null position, the control ports are blocked and fluid is not allowed to flow to the system actuator. When a command signal causes the spool to move off of center, a pressure path is opened at one end of the actuator cylinder and a return path is opened at the opposite end, thereby causing a differential pressure on the piston resulting in actuator force and/or motion.

Hydraulic System

Hydraulic power for the seismic test system is provided under control from the control system. The primary components of a typical hydraulic system are Hydraulic Power Supplies (HPS), Hydraulic Service Manifolds (HSM), and accumulators. Hydraulic fluid from the HPS system is distributed to and from the servovalves that control movement of the actuators.

A 125 gallon accumulator stand supplies oil for peak flow demands. Valves on the accumulator stand allow the stand to be enabled or disabled depending on the test requirements.

125 gallon Accumulator Stand

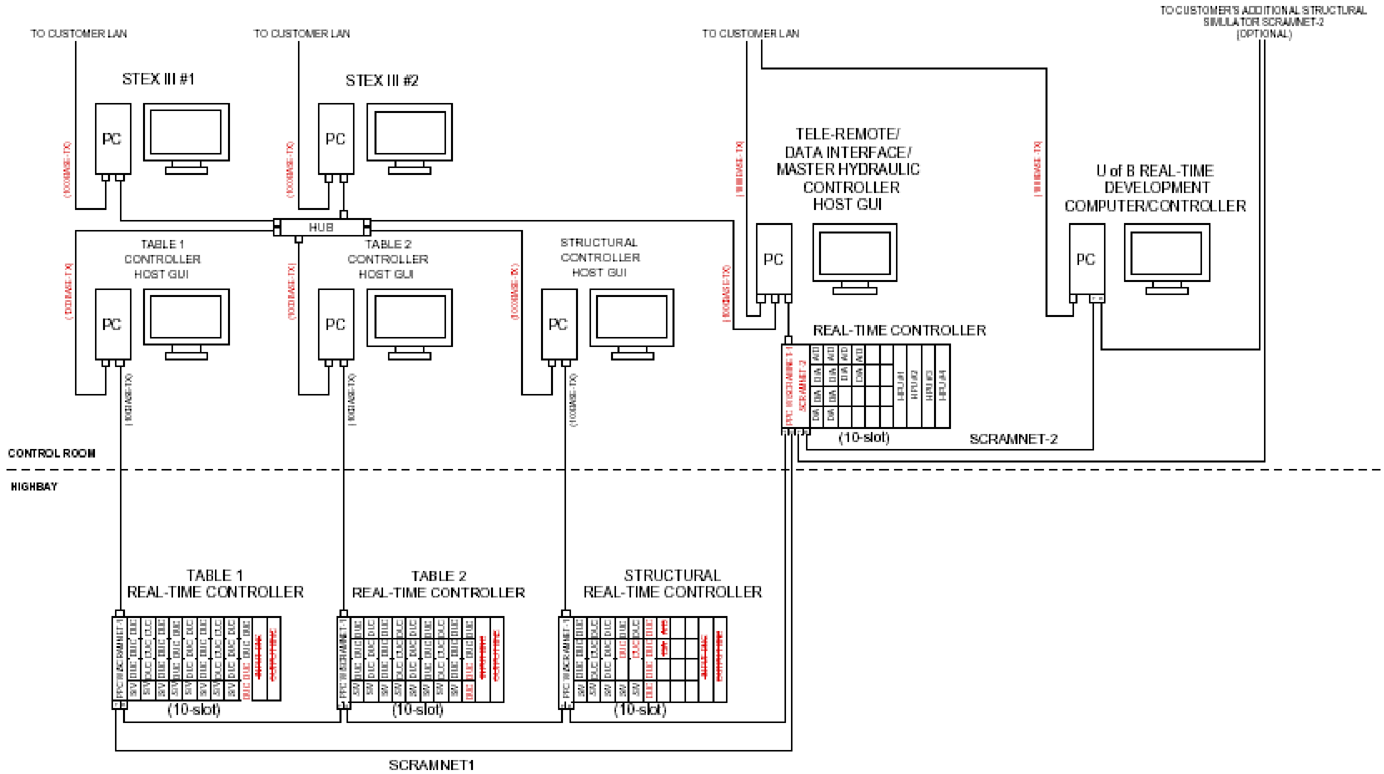
Static Support

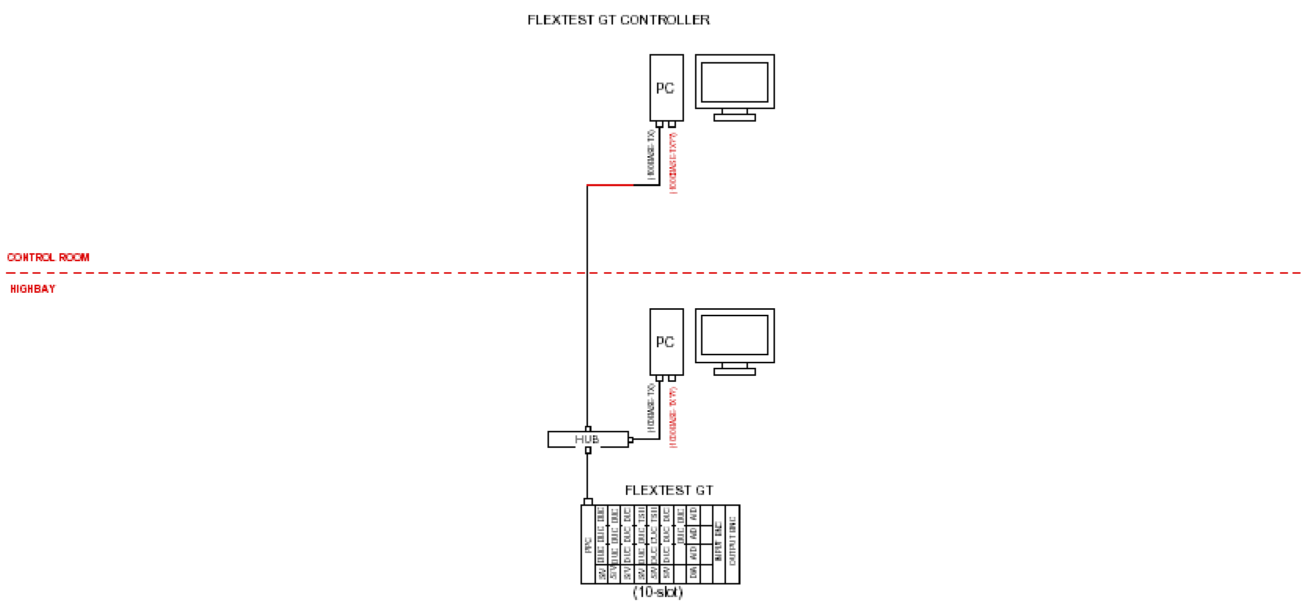
The vertical actuators have a have an integrated static support system that supports the static weight of the table and specimen by applying pressure to the end of the piston rod. The static support force is changed by commanding a pair of solenoid valves to allow pressurized oil in or out of the static support chamber until the ΔP transducer reads zero differential pressure.

A large accumulator is attached to the static support chamber to hold the static support pressure nearly constant while the actuator piston moves. When properly adjusted, the static support system allows the actuator cylinder to provide only the dynamic motion, thus improving the control system dynamic response.

Control System

A drawing of the control system is displayed below.





The control system consists of MTS console assemblies, associated cabling and control software. An MTS console assembly has an imbedded processor and real-time hardware. The control software consists of the real-time control software and the control panel software. The real-time control software drives the processors to generate command and error signals. The control panel software runs on a PC and has a graphical user interface consisting of interactive, modeless dialogs that are used to enter system parameters and execute a test.

The seismic table system includes two Table Controllers, a Master Hydraulic Controller, and a Flextest GT Controller. Several PCs are provided to run the various software packages.

469D Table Controllers

The 469D Digital Seismic Table Controllers are real-time, 6 DOF, digital controllers that provide three-variable-closed loop control along with adaptive control. They also provide an operator interface to the real-time hardware. The control hardware architecture is based on Digital Signal Processing technology that optimizes the performance of the embedded control system, and allows for the implementation of advanced control and data filtering operations.

The controller consists of a MTS console assembly, associated cabling and control software. The MTS console assembly has an imbedded processors, real-time hardware. The control software consists of the real-time control software and the control panel software. The real-time control software drives the processors to generate command and error signals using state-of-the-art Three-Variable-Control (TVC). The control panel software runs on a PC and has a graphical user interface consisting of interactive, modeless dialogs that are used to enter system parameters and execute a test.

The 469D digital controller provides the following features:

- Degree of Freedom Control
- Three-Variable Control (TVC)
- Adaptive Control
- Differential Pressure Stabilization
- Force Balance Compensation

Motion of the multiaxial table is governed by the collective movement of all system actuators. To create a desired table motion, actuator motions are time-synchronized using the patented **Degree of Freedom** (DOF) control concept. This concept allows the user to control system motion in a coordinate domain most natural to the test. There are six degrees of freedom; vertical, lateral, longitudinal, yaw, pitch and roll.

The **Three-Variable Control** concept is utilized to provide flat performance across the broad frequency range of a typical seismic test system. TVC is critical for high fidelity and high bandwidth control.

TVC provides simultaneous control of displacement, velocity, and acceleration, emphasizing displacement at low frequencies, velocity at middle frequencies, and acceleration at high frequencies.

As components age and their effects change, these changes alter the total effect of the system, so that a given command no longer produces the expected response. **Adaptive control** techniques are effective tools to use to counter parameter changes in system components. Adaptive control techniques include Amplitude/Phase Control (APC), Adaptive Harmonic Cancellation (AHC), Amplitude Inverse Control (AIC), and Online Iteration (OLI).

Differential Pressure Stabilization control technologies are critical for high performance. Differential Pressure Stabilization effectively dampens oil column compliances that occur with heavy mass loads, by feeding a signal proportional to actuator force into the control loop. This technique allows for stable operation over a much wider range of gain settings.

When multiple actuators are used to meet the force or velocity requirements of seismic tables, the system becomes "over-constrained". Over-constrained systems are inherently subject to undesirable force imbalances which can seriously limit the performance of the table. **Force Balance Compensation** corrects for this by balancing the force generated by each actuator against a weighted average of the other actuators in the same degree of freedom. This ensures that the force is distributed equally among all driving actuators and that the full force capability of the actuators is available to drive desired table motion.

Master Hydraulic Power Controller

The Hydraulic Power Controller is used to control the 4 HPS's and 4 accumulator banks.

MTS Seismic Test Execution (STEX) Software

In conjunction with the digital system, the STEX software provides test waveform creation and data storage functions. It acts as the primary test waveform source for the test system, and provides data acquisition, processing, and storage functions for the system motion and specimen response data acquired during testing.

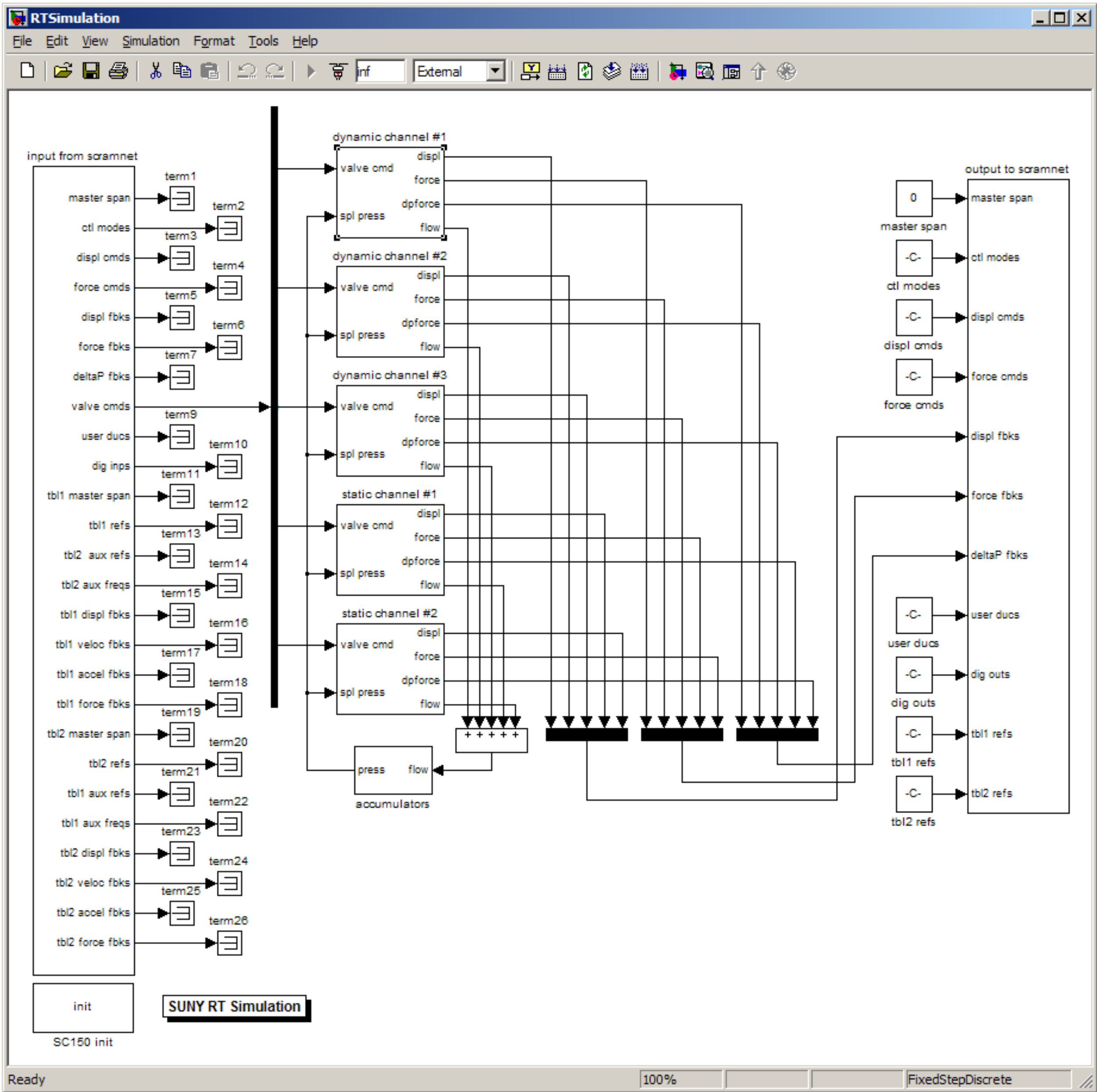
Scramnet®.

***NOTE**: Refer to **Appendix A** for a list of Scramnet signals and parameters.*

Mathworks' Simulink® dynamic simulation programming environment has been integrated into MTS's controller architecture. Signals pass between MTS's controllers and the Simulink realtime PC in digital form over Scramnet®. This open environment allows you to create Simulink dataflow programs that interact with MTS's control software in realtime. All controller feedbacks are made available for use in Simulink, while commands or controller correction signals generated by Simulink drive MTS's controller command inputs. Some things that you can do with this capability are:

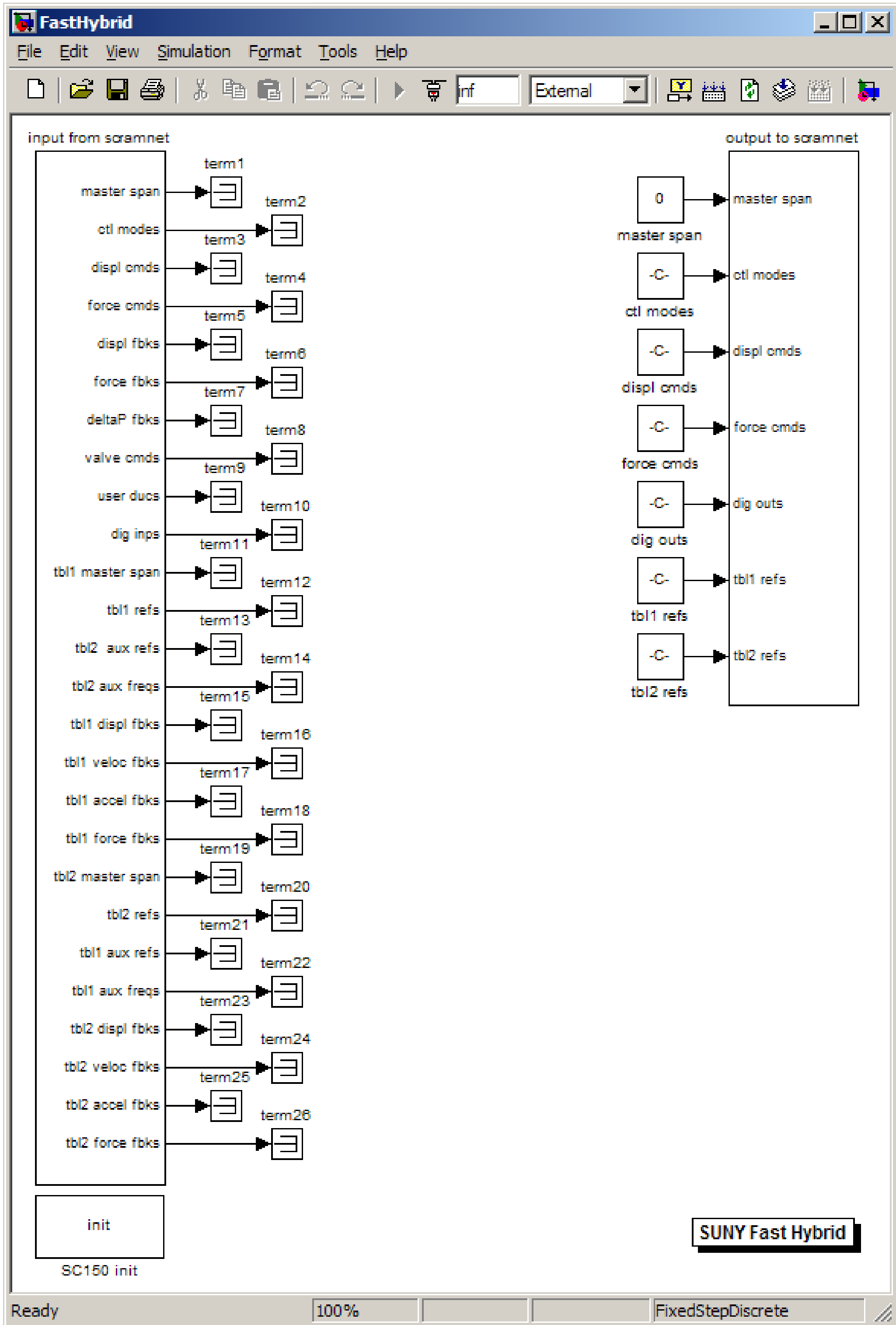
- Develop your own control algorithms to augment or replace MTS's.
- Develop a realtime simulation of your system's dynamics for purposes of algorithm checkout, performance prediction, offline control system tuning, and test rehearsal.

RT Simulation



- Test "hybrid" structures, consisting of a real structure on the table and a "virtual" structure in the computer. For example, your real structure can be the lower floors of a multistory building, and the virtual structure the upper floors. As the lower floors are being shaken on the table, the affect of the upper floors on the lower floors can be computed in realtime in Simulink, and a command signal sent back to the MTS controller to drive actuators attached to the top part of the real structure to create those interaction forces.

FastHybrid

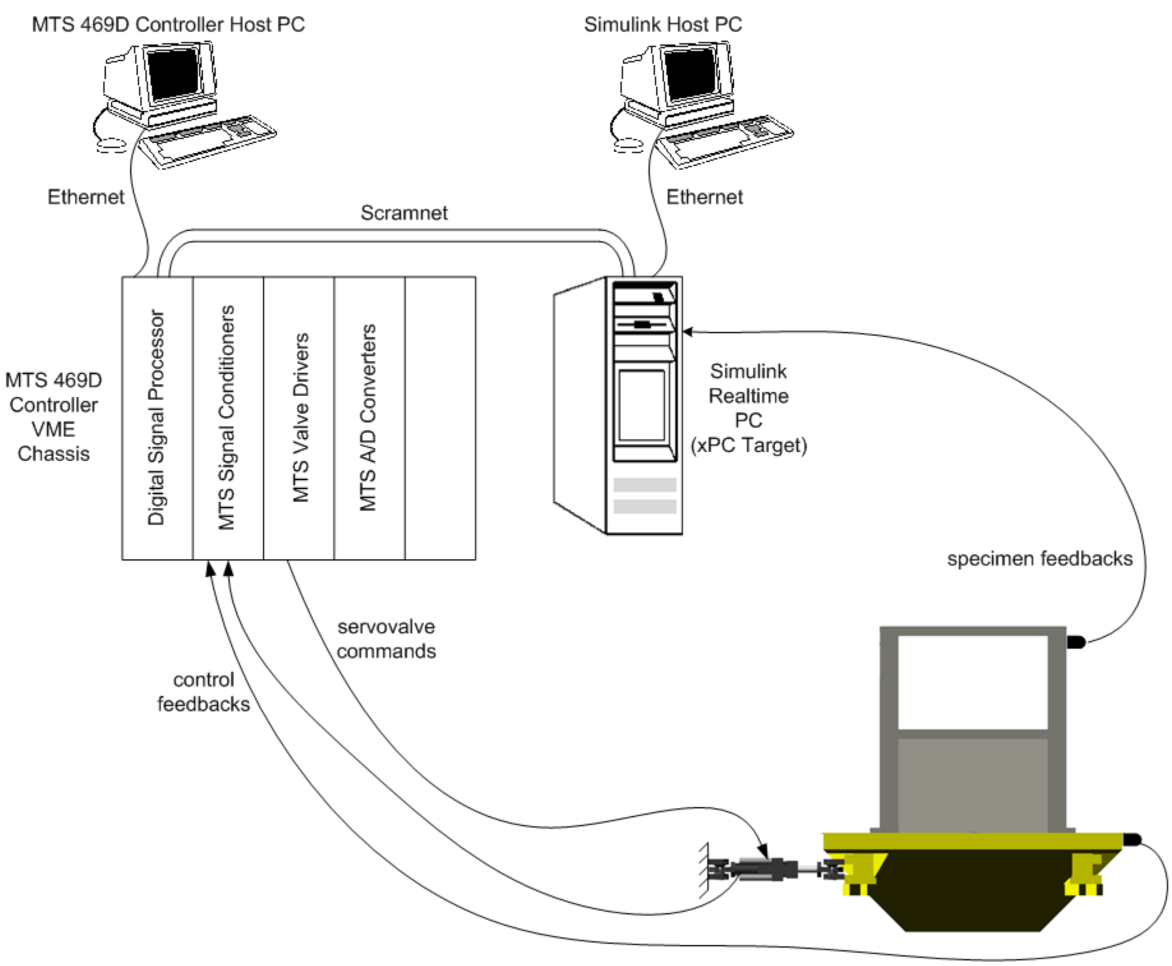


FastHybrid
File Edit View Simulation Format Tools Help
inf
External
input from scramnet
master span
ctl modes
displ cmds
force cmds
displ fbks
force fbks
deltaP fbks
valve cmds
user ducs
dig inps
tbl1 master span
tbl1 refs
tbl2 aux refs
tbl2 aux freqs
tbl1 displ fbks
tbl1 veloc fbks
tbl1 accel fbks
tbl1 force fbks
tbl2 master span
tbl2 refs
tbl1 aux refs
tbl1 aux freqs
tbl2 displ fbks
tbl2 veloc fbks
tbl2 accel fbks
tbl2 force fbks
term1
term2
term3
term4
term5
term6
term7
term8
term9
term10
term11
term12
term13
term14
term15
term16
term17
term18
term19
term20
term21
term22
term23
term24
term25
term26
init
SC150 init
output to scramnet
0
-C-
master span
ctl modes
displ cmds
force cmds
dig outs
tbl1 refs
tbl2 refs
SUNY Fast Hybrid
Ready
100%
FixedStepDiscrete

Hardware

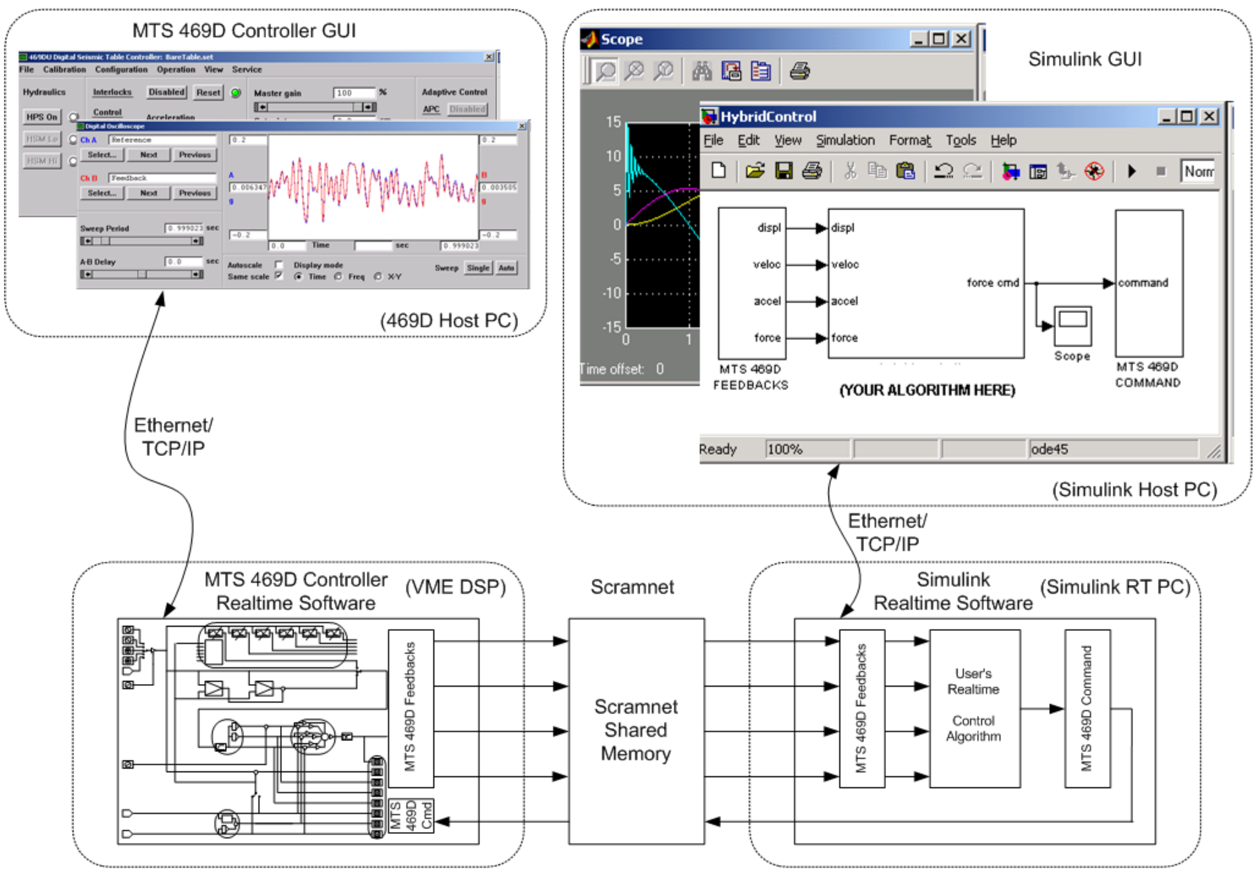
A diagram of a typical control system hardware is shown in the figure below, using a seismic table as an example. MTS's controller consists of a host PC connected to a VME chassis containing signal conditioners, valve drivers, and a high performance digital signal processor. The Simulink realtime model runs on a high performance PC after being downloaded by its host PC. The Simulink realtime PC is a standard Windows PC that you can easily upgrade to higher performance PCs as they become available. In order to guarantee realtime performance, the PC is booted with a floppy disk containing a special realtime kernel; the Windows operating system does not exist while this kernel is running.

Signals pass between MTS's controller and the Simulink realtime PC in digital form over Scramnet®. Scramnet creates a section of memory that both the MTS controller DSP and the Simulink realtime PC can access, allowing them to pass signals to each other simply by writing and reading this block of shared memory.



Software

A diagram of a typical control system from a software standpoint is shown in the figure below. You create your model on the Simulink host PC by drawing a dataflow diagram that represents your control algorithm, system dynamics, hybrid simulation, or whatever. Then with a click of a button, Simulink will compile your diagram, download it to the Simulink realtime PC, and run it. MTS provides a template model diagram that gives access to all controller feedbacks and command inputs. You insert your model inside the "YOUR ALGORITHM HERE" box. If you add third-party interface hardware to the Simulink realtime PC, Simulink provides software to access a wide range of hardware devices.



Section 2

Operator's Safety Practices

Overview

This section contains general operating safety techniques and precautions for operators of MTS testing systems. Your testing system operates within a unique environment that includes:

- Facility utilities, including mechanical and electrical equipment and atmosphere
- Test specimens
- Operator experience and specializations
- Equipment modifications you make to perform specific tasks

Because of these variables, the system could operate under unforeseen circumstances, resulting in an operating environment with unknown hazards. Common sense and a thorough knowledge of the system's operating capabilities usually suggest the appropriate approach to system operation.

In addition to reading these guidelines, you should also read all supplied manuals. Anyone who operates an MTS system should also have had prior schooling and training on similar systems. MTS has training facilities for system operators and maintenance personnel to provide experience and training on MTS products.

General Guidelines

The following operating safety considerations are applicable to most systems. As you read each item, consider your system to ensure that your operating environment and procedures do not result in hazardous situations. Although complete elimination of hazards may not be possible in a laboratory environment, the following guidelines can help identify hazards so appropriate training, operating procedures, and safety equipment can be implemented. Contact an MTS representative if you have any questions.

Read all Provided Manuals

System operators should gain an understanding of the system functions by studying the various drawings and product manuals in the system reference manual set. The reference manual set includes an Assembly Drawings manual and a Product Information manual. These drawings and manuals provide a good background for the structure and operating principles of the system.

Review Operation Procedure

Before operating the system for the first time, make a trial run through all operating procedures to locate and become familiar with all of the appropriate controls. If any operating adjustment seems unclear, review the operation and adjustment procedures listed in the associated product manual. If you need additional information, you can contact MTS for technical assistance.

Special points to consider when reading the manuals include:

- Locate all caution and warning notices for the known hazard characteristics of your system. These notices are located in the standard hardware product manuals provided in the system Reference Manual.
- Refer to the Operation Manual for step-by-step system operating procedures. If the operating procedures for your system change due to component modifications or other reasons, mark the changes in this manual to reflect the proper procedure.

Read Safety Placards

Locate, read, and follow all instructions on equipment safety placards.

Locate Emergency Stop Buttons

Locate all system Emergency Stop (or E-STOP) buttons on the system so you can quickly stop system operation in an emergency situation.

Use Eye Protection

Use adequate eye protection when working with system fluids or near an operating system.

Stay Clear of System When Running

Never enter the test area while the test is in progress. Do not approach or touch the test specimen when the system is running. Ensure that hydraulic pressure is removed from the system before entering the test area.

Clean Work Area

Always keep work area floors clean. Spilled hydraulic fluid on any type of floor surface is dangerously slippery.

Know Effects of all Adjustments

Do not make any mechanical or electrical adjustments to system components unless you know exactly how the adjustment will affect system operation. Consult your MTS representative if in doubt about any adjustment procedure.

Ensure Interlocks Work

System interlock devices should always be used and properly adjusted. Test all interlock devices for proper operation before starting a test. Due to the possibility of operator error, misadjustments, or component failure, interlock devices must not be relied on to protect personnel. These devices are primarily designed to minimize the chance of accidental damage to test specimens and test equipment.

Avoid Moving Cables and Hoses

Stay clear of cables and hoses that move along with the test specimen or equipment. Objects may get tangled or dragged along with such cables and hoses. Serious injury can be inflicted by a fast moving cable or hose.

Avoid High Voltage Areas

High voltage is present inside the system control consoles. Avoid exposure to these areas when electrical power is applied. Avoid touching any exposed wiring or contacts anywhere in the system.

Use Care When Charging Accumulators

Systems that use pneumatic devices (such as accumulators and static supports) contain high-pressure gas that is very hazardous if improperly handled or poorly maintained. Read all gas cylinder labels to properly identify the type of accumulator and the type of gas to use. Follow all charging instructions given in the appropriate manuals. When charging accumulators, use only dry nitrogen. (Dry nitrogen can be labeled "oil pumped" or "dry water pumped.") Do not use oxygen in place of nitrogen. If oxygen comes in contact with pressurized hydraulic fluid, a highly explosive condition will exist. Contact your MTS representative if in doubt about any charging procedure.

Maintain Electrical Cables in Good Condition

Protect electrical cables from spilled hydraulic fluid and from excessive temperatures that can cause cable hardening and eventual cable failure. Clean spilled hydraulic fluid from electrical cables as soon as possible. Inspect cables for cuts, exposed wires, or other types of damage prior to system operation. Ensure that cable connectors are securely plugged into their respective receptacles. Remove system electrical power before replacing a defective cable. Ensure that all cables have appropriate strain relief devices installed.

Use Care When Routing Cables and Hoses

Protect all system cables and hoses from sharp or abrasive objects. Never walk on hoses or cables or move heavy objects over them. Route hoses and cables away from areas that expose them to possible damage.

Check Hoses and Cables

Thoroughly inspect hoses for blisters, cuts, or other damage prior to system operation. Replace damaged hoses or cables. While the system is operating, inspect all hoses and cables to ensure that there is no excessive thrashing, bending, or chafing that could cause cable or hose damage.

Be Aware of Servovalve Silting

Because of servovalve silting, an actuator can develop random instability or erratic operation at unusually low hydraulic pressure levels (such as bypass). This is even more common if the system uses large servovalves or the hydraulic fluid is dirty. Contact MTS for information on hydraulic fluid maintenance procedures.

Flush Hydraulics

Flush the hydraulic system immediately after any of the system's hydraulic components have been replaced, or the system configuration has been changed. Contact MTS for information on hydraulic fluid maintenance procedures.

Use Caution When Handling Fire Resistant Hydraulic Fluids

Special safety considerations are necessary when operating a system that contains any type of fire resistant hydraulic fluid. These fluids are toxic and present a lethal situation if the fluid is accidentally swallowed or if a sufficient amount of fluid is absorbed through the skin. Avoid contacting fire resistant fluid. Do not mix fire resistant fluid with petroleum-based fluids. Also, do not add fire resistant fluids to systems that are not compatible with these types of fluids.

Avoid System Crush Points

Stay away from any potential crush points, especially when the system is running. The system is capable of producing very high forces within a fraction of a second. Never assume that human reaction time is fast enough to escape injury. Know where the crush points are on your system and protect yourself and others with appropriate safety devices.

Use Care When Installing Test Specimen

Test specimen installation is potentially the most hazardous part of system operation. You are very close to or in contact with the system force train during installation. Exercise great caution to avoid crush points. Be sure to follow all provided installation instructions along with the following:

- Clear the work area, especially near crush points.
- Balance the servo control loop (reduce dc error to zero), use low hydraulic pressure, and ensure that the servo control system is stable. Be particularly alert for phase or control reversal if the system setup has been modified since the last time the system was operated.
- Do not bump, wiggle, adjust, or otherwise disturb a transducer that provides a feedback signal to the control system.

Hazards Related to Unexpected Actuator Reactions

Destructive forces can be generated from unexpected actuator response. Likely causes of such response are operator error and equipment failure (broken cables, damaged hoses, damaged electrical components, etc.). An actuator piston rod that reacts unexpectedly can strike an operator, or cause expensive equipment damage. Anyone who must be close to the system while hydraulic pressure is applied should acquire a thorough knowledge of the system's operating characteristics.

The following examples are some of the most probable causes of an unexpected actuator reaction.

Loss of Control Mode Feedback

If the control mode feedback signal is interrupted during operation, the active Controller senses a dc error. The actuator will then attempt to correct the error by stroking (at maximum velocity) until it reaches an internal or external mechanical limit. The external limit may be anything in its path (tools, specimens, or hands). Be aware that the full force of the actuator will be applied to that external limit or obstruction. Also, be aware of the following special points regarding the force-producing characteristics of hydraulic actuators:

- A selectable operating range does not reduce the static force capability of a hydraulic actuator. It only increases or decreases the sensitivity of the electronic control and readout components.
- The only way to effectively minimize the static force capability of a hydraulic system is to reduce the system hydraulic pressure.
- The control mode feedback originates from a transducer located in the system, and is transported to the control electronics through a transducer cable. This cable must be protected from damage to minimize the chance of unexpected actuator reaction. If the cable is routed around corners or through wall openings, ensure that all sharp edges are padded. Ensure that this cable has appropriate strain relief devices installed.
- The error detectors in the control electronics minimize the potential for equipment damage caused by loss of feedback or larger-than-normal dc errors. Do not rely on these circuits to protect personnel.

Loss of Servovalve Control Signal

An open control loop results if the cable from the control electronics to the servovalve is broken or disconnected while hydraulic pressure is applied to the system. The response of the actuator will depend on several different factors (piston rod position, the servovalve in use, etc.). In any case, actuator reaction can be violent. The same precautions that apply to transducer cables must be observed for servovalve cables.

Program Interruption and Step Functions

The composite command signal for the servo control loop usually consists of several program inputs such as program, command, setpoint, span, and master span. If one of these inputs is inadvertently removed or suddenly changed, the servo loop will detect a large instantaneous dc error and the actuator will respond accordingly.

Applying Hydraulic Pressure with a Command Present

When hydraulic pressure is not applied to the system, the actuator can drift down to its endcap unless restrained in some manner. If hydraulic pressure is applied again and the system is operating in static control, the actuator will quickly return to its previous position. The setting of the active **Setpoint** control is the determining factor in most cases. Always adjust the active **Setpoint** control to zero the servovalve command before applying hydraulic pressure.

Do not use any interlock reset to bypass the interlock chain and attempt to apply hydraulic pressure. Doing so will apply hydraulic pressure to the system regardless of the interlock condition.

Electrical Power Failure or Shutoff

Turning off electrical power, or an electrical power failure when hydraulic pressure is applied to the system, can cause considerable and unpredictable actuator reactions. Loss of electrical power generally causes the actuator to stroke at maximum velocity in either direction.

Over Programming

Unexpected actuator movement or excessive actuator force can result from operator error when adjusting a **Setpoint** or **Span** control. The composite command to the servo control loop is the algebraic sum of the signals produced by these controls. Either **Setpoint** or **Span** can program 100% of the system force producing capability. For example, in most systems a 10-volt signal produces full-scale response. If the program input to the control electronics is a 10-volt sine wave and **Span** is adjusted to 100%, any mean level offset introduced by the **Setpoint** control causes the command to exceed the capabilities of the system.

Section 3

Understanding Control Principles

Overview

This section contains information on the control principles used in the 469D control system. The following topics are discussed:

- Actuator Control Concepts
  - Basic Closed-Loop Control
  - Inner and Outer Closed-Loop Control
  - Three-Variable Control
- Table Control Concepts
  - Table Motion
  - Table Polarity
  - Degree of Freedom Control
- Compensation Techniques
  - Force Balance Compensation
  - Differential Pressure Stabilization
  - Velocity and Acceleration Lead Terms
- Test Adjustments
  - Master Gain
  - Span
  - Setpoint
- Limit Detection
- Adaptive Control
  - Amplitude/Phase Control
  - Adaptive Harmonic Cancellation
  - Adaptive Inverse Control
  - Online Iteration

Before setting up the test system or executing a test, it is important that you fully understand these control elements.

Actuator Control Concepts

Motion of a seismic table is governed by movement of its collective actuators. Each actuator in an MTS seismic test system is controlled through basic closed-loop, inner and outer closed-loop, and three-variable control concepts. These basic servohydraulic control concepts are discussed in the following subsections.

Basic Closed-Loop Control

In general, closed-loop control consists of comparing a command signal with a feedback signal.

Consider the system schematically illustrated in Figure 3-1. In this system, a displacement command signal is generated by a program source that is outside of the control loop. Feedback is generated by a linear variable differential transformer (LVDT).

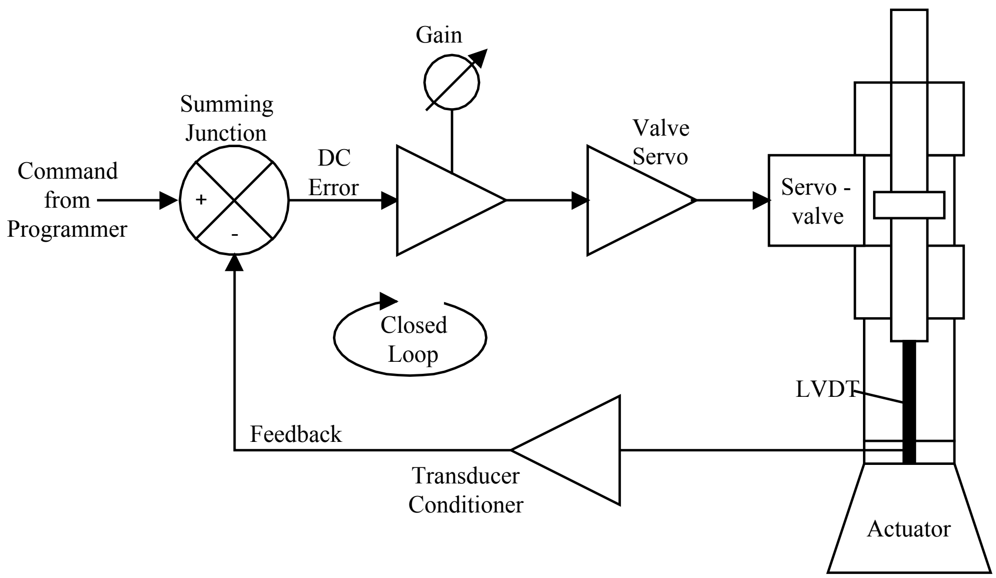


Figure 3-1. Basic Closed-Loop Control

The polarity and magnitude of the dc error signal derived by the command/feedback comparison causes the servovalve spool to open in a direction and by an amount necessary to cause the desired actuator response. As the actuator responds, feedback approaches command. As the program input changes, the command/feedback comparison continuously generates dc error signals that drive the servovalve to create the desired actuator displacement. When command and feedback are equal, the dc error is reduced to zero, the servovalve spool closes, and the actuator does not move. This control method is referred to as "closed-loop control."

Inner and Outer Closed-Loop Control

The simplest form of closed-loop control, as described in the preceding subsection, is used in systems containing a standard one-stage servovalve. However, the large flow and frequency response requirements of seismic testing require the use of a multi-stage servovalve. The multi-stage servovalve (Figure 3-2) contains a spool LVDT that introduces a second loop into the basic closed-loop control system; the basic closed loop described above becomes an "outer" loop and the second loop becomes an "inner" loop.

The MTS Model 252 servovalve is used solely to drive the slave-stage spool. The spool LVDT provides a signal that is proportional to the position of the spool and that is, therefore, approximately proportional to the output flow of the servovalve.

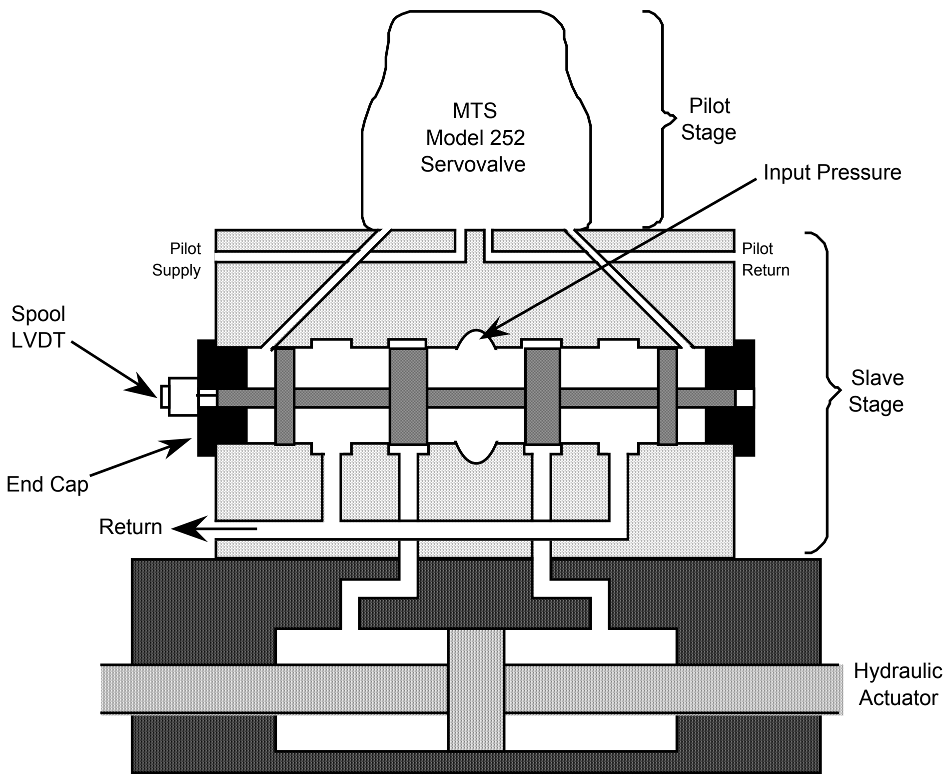


Figure 3-2. Multi-Stage Servovalve

Figure 3-3 schematically illustrates the inner and outer closed-loop control concept. As shown, the outer loop is similar to the basic closed-loop control concept discussed in the previous subsection. The dc error generated in the outer loop is the same as the dc error signal of the basic closed loop illustrated in Figure 3-1. This dc error signal is then applied to the inner loop as a valve command signal.

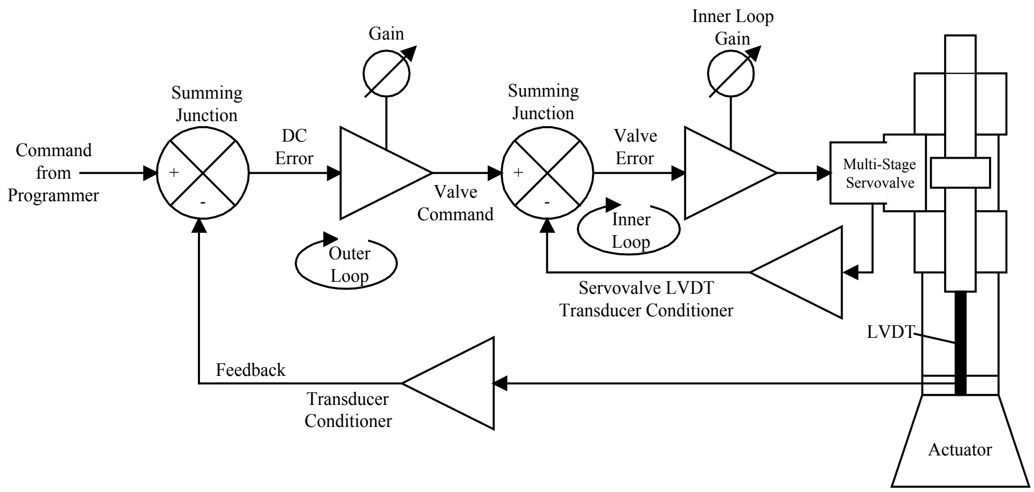


Figure 3-3. Inner and Outer Loop Control

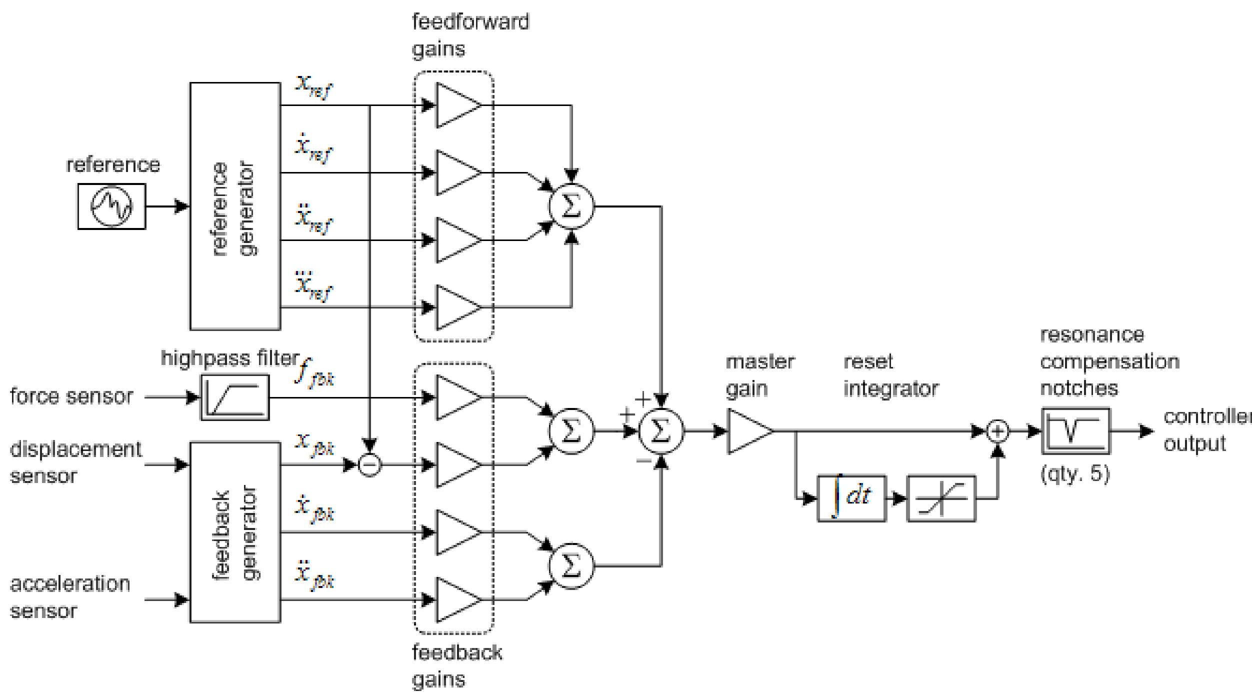
The inner loop controls the position of the slave-stage spool in the same manner that the basic closed-loop concept controls the actuator. The inner loop summing junction produces a dc error signal that drives the slave-stage spool in the desired direction. This second loop enhances closed-loop performance to meet the hydraulic flow and frequency response requirements of seismic testing.

Three-Variable Control

The controlled variable in the examples of closed-loop control discussed in the previous sections is displacement. Two other control variables common to conventional closed-loop seismic test systems are velocity and acceleration. Using a single control variable (whether it is displacement, velocity, or acceleration) cannot provide flat performance in the broad frequency range of the typical seismic test system. Therefore, MTS utilizes all three of these control variables in seismic systems through application of the three-variable control (TVC) concept.

Three-Variable Control (TVC) is what is known in control theory literature as *state variable control*, with additional special features. The three state variables that TVC can control are displacement, velocity, and acceleration. It is a common misconception that all three state variables are controlled simultaneously. The truth is that only one state variable is the primary control variable, with the others serving only as compensation signals to improve damping and stability.

A detailed view of the internal structure of TVC is shown below:

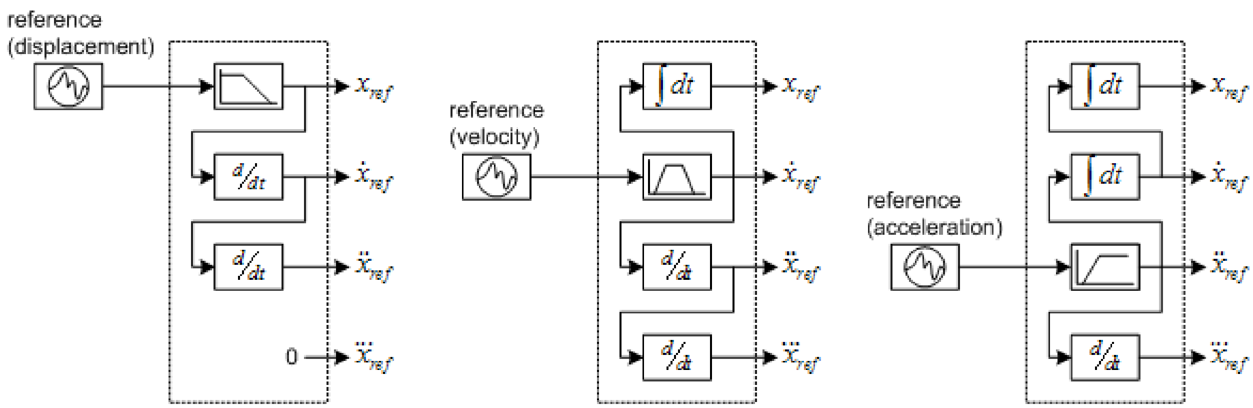


Internal Structure of Three Variable Control

On the reference side, the Reference Generator takes the reference signal, which represents desired displacement, velocity, or acceleration depending on control mode, and creates the reference states x_{ref}, $\dot{x}_{ref}$, $\ddot{x}_{ref}$, and $\dddot{x}_{ref}$. On the feedback side, displacement and acceleration sensors are combined by the Feedback Generator to create the feedback states x_{fbk}, $\dot{x}_{fbk}$, and $\ddot{x}_{fbk}$. In addition, the force sensor output is highpass filtered to remove its static force component and the result used as a stabilization signal to suppress the oil column resonance. Note that even though there are more than three state variables, the name "*Three-*Variable Control" is retained for historical reasons.

The reference and feedback states are weighted by feedforward and feedback gains, respectively, and summed together. The sum is scaled by the Master gain, which is used to quickly reduce all gain effects in order to recover control of the system should it become unstable. The result is integrated and added to itself to provide rejection of static offsets in the system. Finally, a series of five notch filters are applied to compensate for oil column and specimen resonances. The resulting controller output is then used to drive the servovalve of a hydraulic actuator.

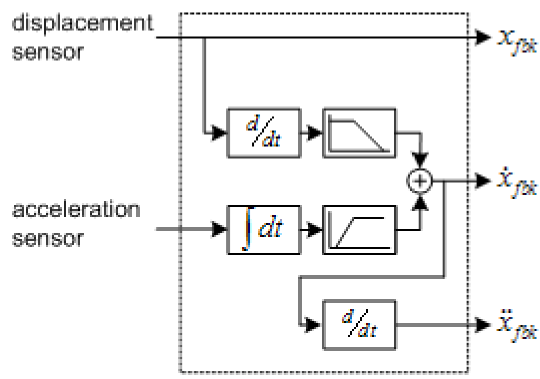
A detailed view of the internal structure of the Reference Generator for each of the three control modes (displacement, velocity, and acceleration) is shown below:



Reference Generator

The reference signal is processed by the Reference Generator as a displacement, velocity, or acceleration signal depending on control mode. In displacement control, the reference is lowpass filtered to form the displacement reference, which is then differentiated to obtain the velocity and acceleration. The jerk reference is not computed and is set to zero. In velocity control, the reference is bandpass filtered to form the velocity reference, which is then integrated to obtain the displacement reference, and differentiated to obtain the acceleration and jerk references. In acceleration control, the reference is highpass filtered to form the acceleration reference, which is then integrated to obtain the displacement and velocity references, and differentiated to obtain the jerk reference. The highpass filtering of the reference that occurs in velocity and acceleration control modes removes static offset and low frequencies from the reference signal to prevent the integrator outputs from becoming too large.

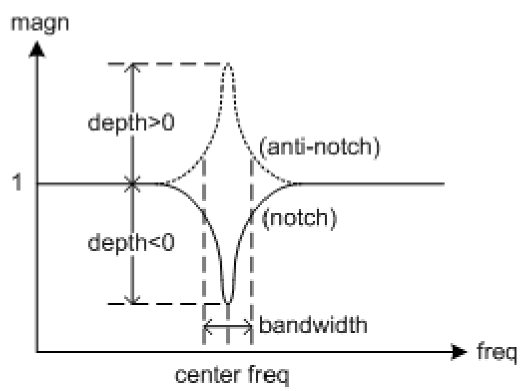
The purpose of the Feedback Generator is to compute wideband estimates of velocity and acceleration feedback from limited bandwidth displacement and acceleration sensors. A detailed view of the internal structure of the Feedback is shown below:



Feedback Generator

To obtain a wideband estimate of velocity, the differentiated displacement sensor signal is combined with the integrated acceleration sensor signal via a crossover filter. The crossover filter ensures that the velocity estimate consists primarily of differentiated displacement at low-to-medium frequencies where the displacement sensor is most accurate, and integrated acceleration at medium-to-high frequencies where the acceleration sensor is most accurate. The wideband acceleration estimate is obtained from the wideband velocity estimate by differentiation. Note that a wideband estimate of displacement is not computed because it is not necessary for control purposes. Instead, the displacement sensor signal serves as the displacement estimate.

The notch filters are used to compensate for resonances and antiresonances. As shown below, the notch filter frequency response is defined by three parameters: center frequency, 3dB bandwidth, and notch depth:



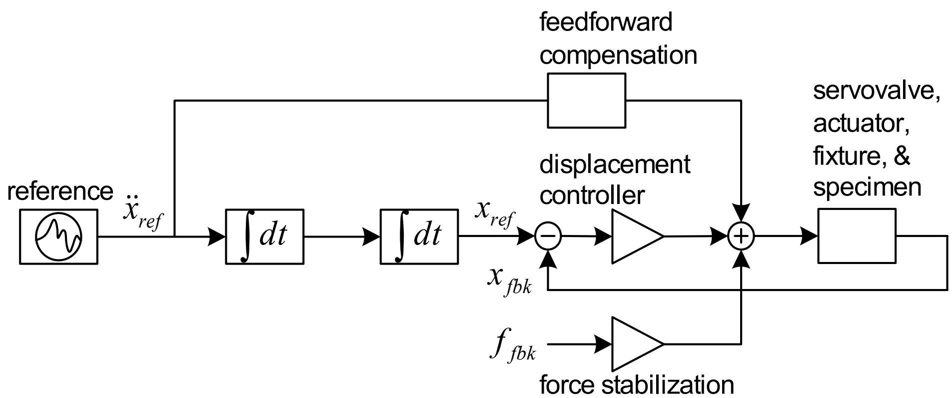
Notch Filter

Note that the notch response at the center frequency can be upward or downward, depending on whether the notch depth is positive or negative. Negative notches are used to suppress resonant peaks, whereas positive notches are used to boost antiresonant valleys. A total of five notches are provided. One notch can be used to suppress the oil column resonance if there is no force feedback in the system. The other four can be used to suppress up to two resonance/ antiresonance pairs.

At first glance it may seem that TVC is very complex because it has so many tuning adjustments. However, it turns out that many of these are not used. For example, as we will see in the upcoming Acceleration Control Tuning section, the acceleration feedback gain is always set to zero. Closed loop servohydraulic control systems do not tolerate acceleration feedback because it has the wrong phase. So we make the following admission:

TVC, as it is used in servohydraulic control systems, is simply a displacement controller with sophisticated feedforward.

The effective topology of TVC as it is used for acceleration control is shown below:



TVC used for Acceleration Control

The topology for velocity control is similar, having only one reference integrator instead of two.

Table Control Concepts

Motion of a seismic table is governed by the collective movement of all system actuators. To create a desired table motion, the individual actuator control concepts discussed in the previous section must be synchronized. MTS achieves this synchronization through application of the degree of freedom (DOF) control concept.

Understanding standard definitions of table motion, DOF coordinates, and table polarity are critical to understanding DOF control. The following subsections provide these definitions and a description of DOF control.

Table Motion

The unrestrained motions of the seismic table are described by six degrees of freedom. These six degrees of freedom, illustrated in the figure below, are defined as follows:

Translational Degrees of Freedom

Longitudinal	Motion along the longitudinal (X) axis
Lateral	Motion along the lateral (Y) axis
Vertical	Motion along the vertical (Z) axis

Rotational Degrees of Freedom

Roll	Rotation about the longitudinal (X) axis
Pitch	Rotation about the lateral (Y) axis
Yaw	Rotation about the vertical (Z) axis

Note that the Dalian system has three unrestrained motions: longitudinal, vertical and pitch. The other three motions (lateral, roll and yaw) are restrained.

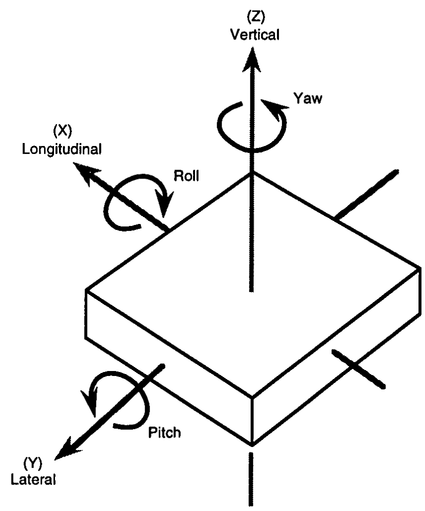
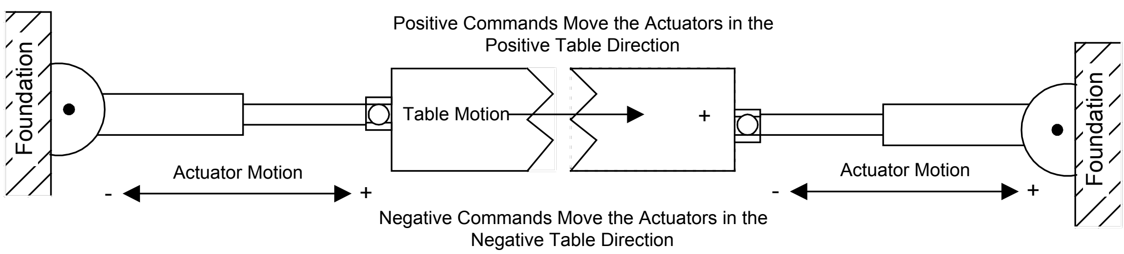


Table Polarity

All actuator movements are defined by positive or negative table movement. As illustrated below, an actuator movement is defined as positive for a motion in the positive direction of table movement.



Although the same DOF coordinate system is applied to most MTS seismic systems, table and actuator polarity is defined on a system-specific basis.

Degree of Freedom Control

Motion of the multi-axial table is governed by the collective movement of all system actuators. To create a desired table motion, actuator motions must be time synchronized. This synchronization is achieved using the Degree of Freedom (DOF) control concept. This control concept allows the user to control table motion in the coordinate domain rather than the actuator domain.
This concept provides the means to account for and control all actuator movements in a given DOF by transforming the feedback signals from all actuators in that DOF to provide DOF feedback inputs. It then transforms all DOF composite error signals to provide coordinated actuator control signals.

Compensation Techniques

The remaining seismic control concepts are methods of compensation and stabilization techniques that improve the fidelity of system performance. The techniques explained in the following subsections are:

- Force Balance Compensation
- Differential Pressure (ΔP) Stabilization
- Velocity and Acceleration Lead Terms

Force Balance Compensation

Force balance compensation is required in systems where more than one actuator affects the control of any translational or rotational axis (that is, where systems are "over-constrained").

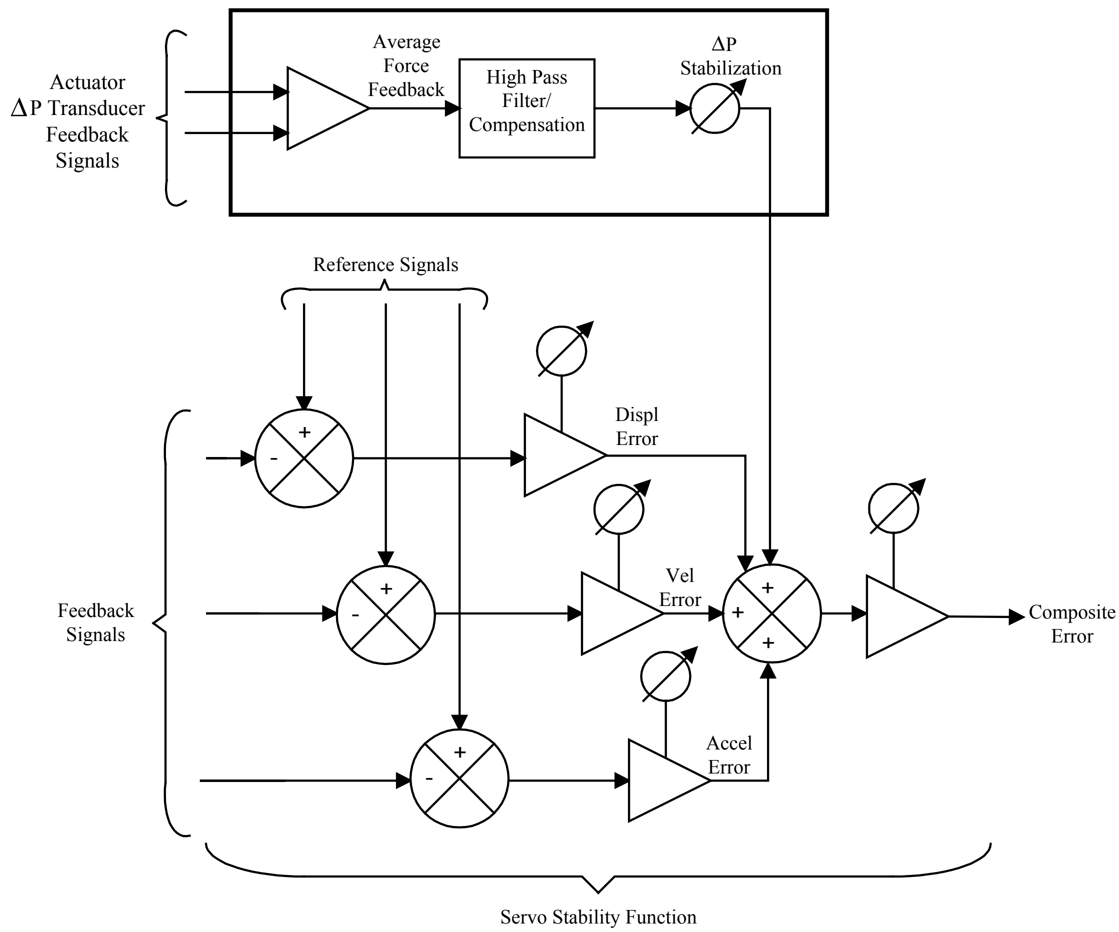
If a table is considered a rigid body, three actuators completely define the plane of the table. A fourth actuator, if not perfectly balanced, may exert large forces to try to distort the stiff table into a shape out of the plane of the other actuators. Therefore, due to the high stiffness of a typical seismic table, small errors in the actuator position can cause large internal table forces to be generated.

This force "imbalance" can seriously limit the force capability of the actuator system. The force balance function compensates for this effect by adding two more degrees of freedom, warp and roll which is controlled to zero using a PID controller.

Differential Pressure Stabilization

Differential pressure stabilization is commonly used in MTS seismic test systems to improve the fidelity of system performance. This function stabilizes the extremely high frequencies encountered during seismic testing to provide more stable acceleration.

Differential pressure (ΔP) stabilization is applied to all electronically-controlled axes. The functional diagram in the following figure illustrates the application of ΔP stabilization in a single degree of freedom.

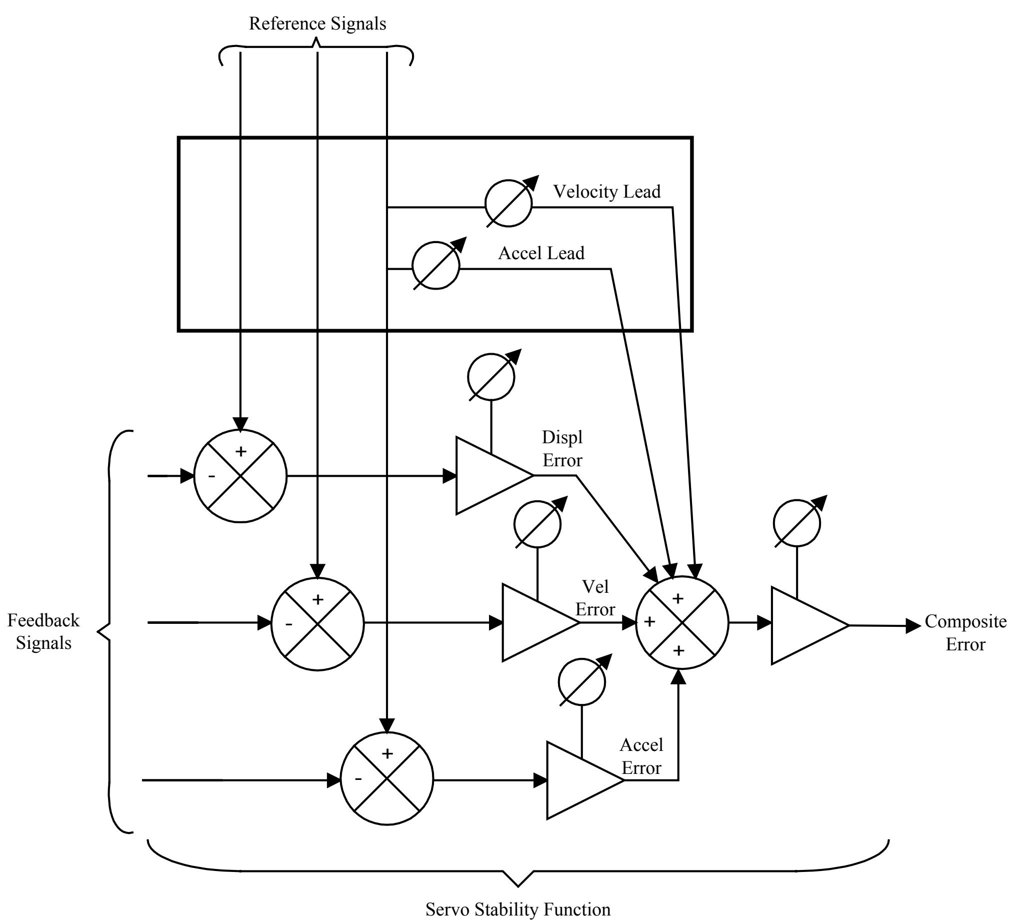

Actuator
ΔP Transducer
Feedback
Signals
Average
Force
Feedback
High Pass
Filter/
Compensation
ΔP
Stabilization
Reference Signals
Displ
Error
Vel
Error
Accel
Error
Feedback
Signals
Composite
Error
Servo Stability Function

Velocity and Acceleration Lead Terms

In a seismic system, where there are large masses and high velocity and acceleration requirements, there is a maximum amount of gain that can be applied to the control loop and still ensure table stability. To enhance system response when it is not possible to apply more gain, MTS seismic test systems contain velocity and acceleration lead terms.

The velocity and acceleration lead terms effectively feed forward an operator-adjusted amount of the command (reference signal) into the composite error signal to provide system performance beyond the optimum stabilized response otherwise available.

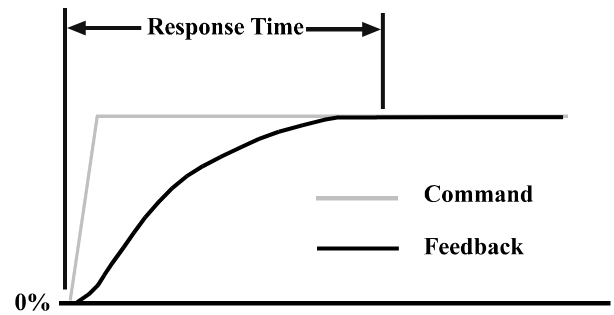
The lead terms can be applied to all electronically-controlled axes. The functional diagram below illustrates the application of the lead terms in a single degree of freedom.



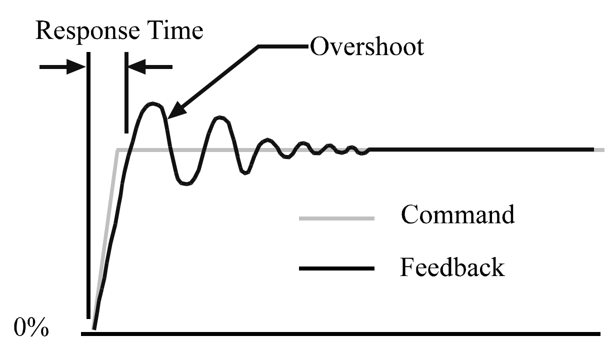
Test Adjustments

Master Gain Adjustment

Master gain is a multiplier applied to the error signal. It determines how quickly the controller responds to error. The greater the gain, the more the servovalve opens for a given error. As master gain is increased, the error decreases, indicating closer tracking of the feedback to the command. The following figure shows a step command and resulting transducer feedback signal with a small gain.



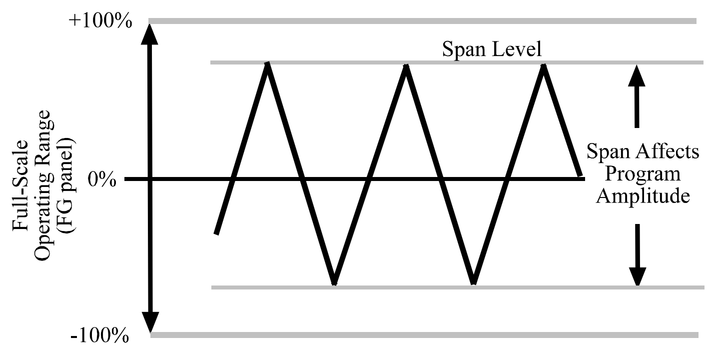
Increasing the master gain decreases the stability margin of the system, increases the frequency of oscillation, and decreases response time. The following figure shows the effect on the transducer feedback of increasing the master gain adjustment.



Setting the master gain too high can result in unstable system operation, causing specimen damage. Master gain should be set high enough to achieve an appropriate response time while maintaining stable system operation.

Span Adjustment

The maximum and minimum amplitude of a waveform output by a programmer is ±10 volts, which represents ±100% of the full-scale operating range. The master span control determines the amplitude of the command signal that is sent to the servo control process.

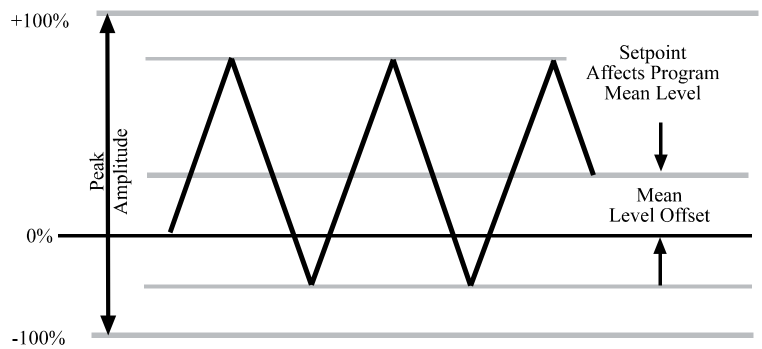


Setting the Span Controls

You set the span controls during test setup to scale the command signal. You can also make minor adjustments to the span control during the test.

Setpoint Adjustment

The maximum and minimum amplitudes of a waveform output by a programmer are ±10 volts, which represent 100% of the peak amplitude operating range. The local setpoint control changes the mean level offset of that program.



Determining Setpoint Position

The setpoint position is the position about which the actuators will move during testing. For seismic testing, setpoint is typically the actuator midstroke position. If a different position is desired, you must ensure that the position does not limit the program capability.

For example, if you adjust a channel setpoint to +75% of the full-scale operating range, then any command that exceeds +25% of the full-scale range will shut down the test system when a full-scale system limit is encountered.

Setting the Setpoint Controls

You set **Setpoint** control during test setup. Refer to Section 6, *Operation*, for procedures used to adjust the setpoint controls.

Limit Detection

Limit detectors can be set to monitor any of the following signals:

- reference signals
- feedback signals
- error signals
- auxiliary signals

Refer to Section 5, *Control Panel Reference*, for additional information about the signal list.

Limit Detector Settings

You set the following parameters for each limit detector: the operating band and a persistence value. The *operating band* defines the allowable range for the signal. The *persistence* value is a time, in seconds, that the signal can remain outside of the operating range before setting an indicator or interlock.

Limit Detector Actions

You can set an action to be taken when a limit or error is detected. The action can be any of the following:

- turn an indicator on
- stop a program signal
- trip the system interlock

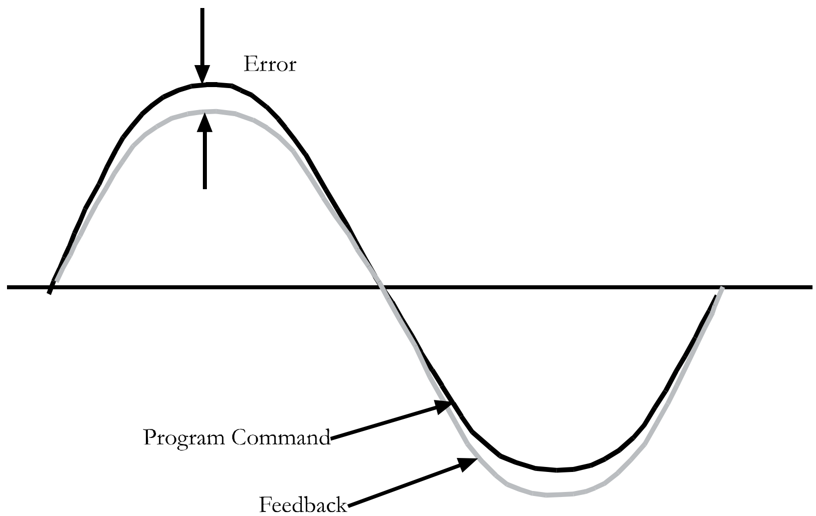
Refer to Section 5, *Control Panel Reference*, and Section 6, *Operation*, for additional information about setting the limit detectors.

Enabling Limits

After setting limit parameters, you enable the limit detectors and choose an action before running a test.

Error Detector

Error detectors are limit detectors that monitor the error signal, that is, the difference between the command and feedback, as shown in the following figure. An error detector can stop the test if an error in excess of the preset level is detected.



The level of acceptable error depends directly on the accuracy requirements of each testing situation.

Setting Error Detectors

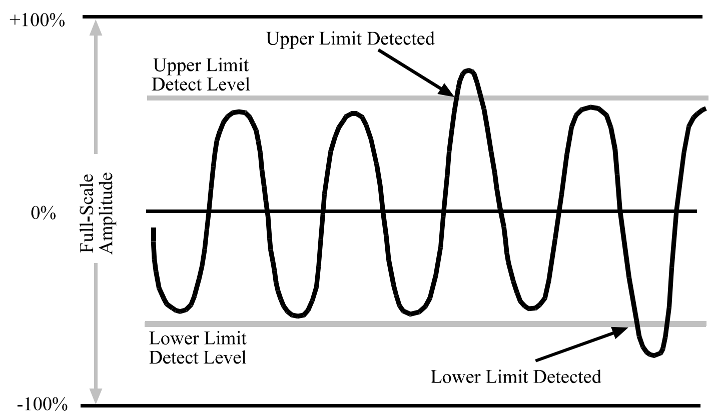
You set the operating band and persistence for the error limit detector.

For static and low frequency testing, the initial error detector levels can be determined before beginning test setup. The level selected should reflect the response requirements of the specific test. For example, if the test can tolerate up to 25% deviation from the program signal, the error detector level can be set to 25%.

The error detector level can also be adjusted during testing if desired. Operator experience is the best guide for adjusting the error detectors for high frequency testing.

Feedback Limit Detectors

Feedback limit detectors monitor the feedback signals. As shown in the following figure, when a feedback signal exceeds its preset upper limit or falls below its preset lower limit, the corresponding limit detector can (if set to hold a program or trip the system interlock) stop the test.



Determining Limit Detector Levels

The limit detectors should be set to minimize the chances of accidental damage to test specimens and test equipment. They are typically set to shut down the system upon specimen failure in order to prevent fixturing or equipment damage. *Under no circumstances should the limit detectors be relied on to protect personnel.*

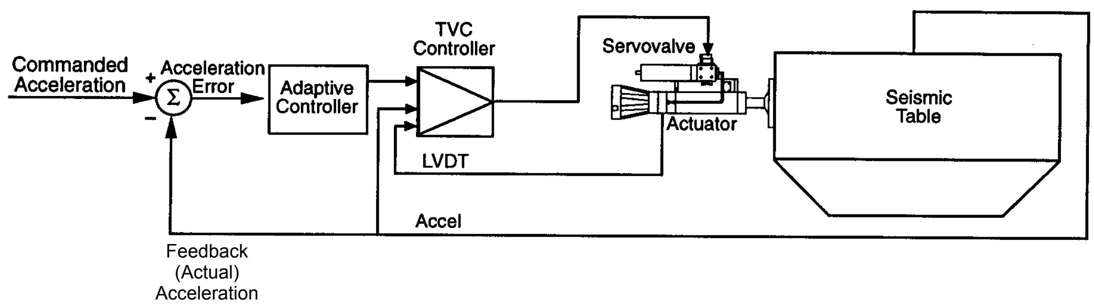
Setting Limit Detectors

You set the operating band and persistence for each feedback limit detector.

A limit event for a particular signal indicates that the signal has exceeded its upper or lower limit. The selected band establishes a range of values that represent a desired system operating range. This band also represents the range where valid test data can be ensured. The persistence value is a time (in seconds) that an upper or lower out-of-limit condition can persist without causing an interlock.

Adaptive Control

In any real-life test system, there are specimen and system mechanical response nonlinearities, the components age and their effects change. These changes alter the total effect of the system, so that a given command does not produce the expected response. To improve the fidelity of the system response, an adaptive controller is introduced into the closed loop, as shown in the following figure.



Adaptive control can include the following techniques:

- Amplitude/phase control—for correcting amplitude and phase errors in sine response waveforms.
- Adaptive harmonic cancellation—for reducing or canceling spurious harmonics that are present in the feedback when the command is sinusoidal.
- Adaptive inverse control—for rapid adaptation to changing system dynamics. It is effective for improving tracking accuracy in mainly linear servohydraulic test systems, for any wave shape.
- Online iteration—intended to complement basic adaptive inverse control, providing a way of handling nonlinear system applications.

These techniques are discussed in more detail in the remainder of this chapter.

Amplitude/Phase Control (APC)

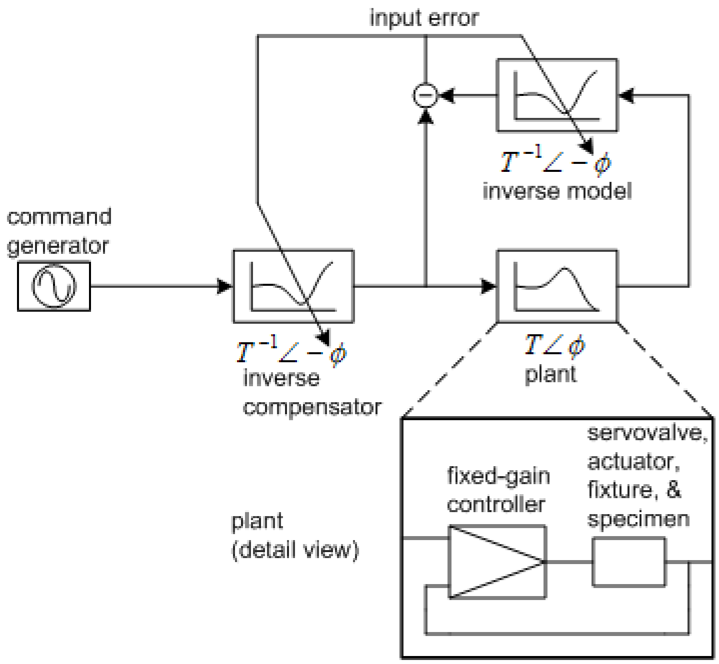
Amplitude/Phase Control (APC) is a control compensation technique that augments a fixed-gain controller to correct for closed-loop amplitude and phase irregularities in order to improve control fidelity. It measures control system dynamics directly and modifies the control compensation accordingly in realtime, making it possible to adapt to changing system dynamics. Amplitude phase control:

- corrects phase errors as well as amplitude errors (important for phased multi-channel testing applications).
- converges quickly to optimum correction because the correction is updated at every point on the sine wave, not just at the peaks.
- works well even with very noisy feedback signals.
- works only with sine wave program signals.

APC is optimized to work with sinusoidal command waveforms (both fixed and swept frequency) and predominantly linear systems. If the command waveform is non-sinusoidal, use Adaptive Inverse Control (AIC) instead. If the system has significant nonlinearities, augment APC with Adaptive Harmonic Cancellation (AHC) to reduce harmonic distortion. APC and AHC complement each other: APC enhances the fundamental frequency component of the system response while AHC cancels the harmonics.

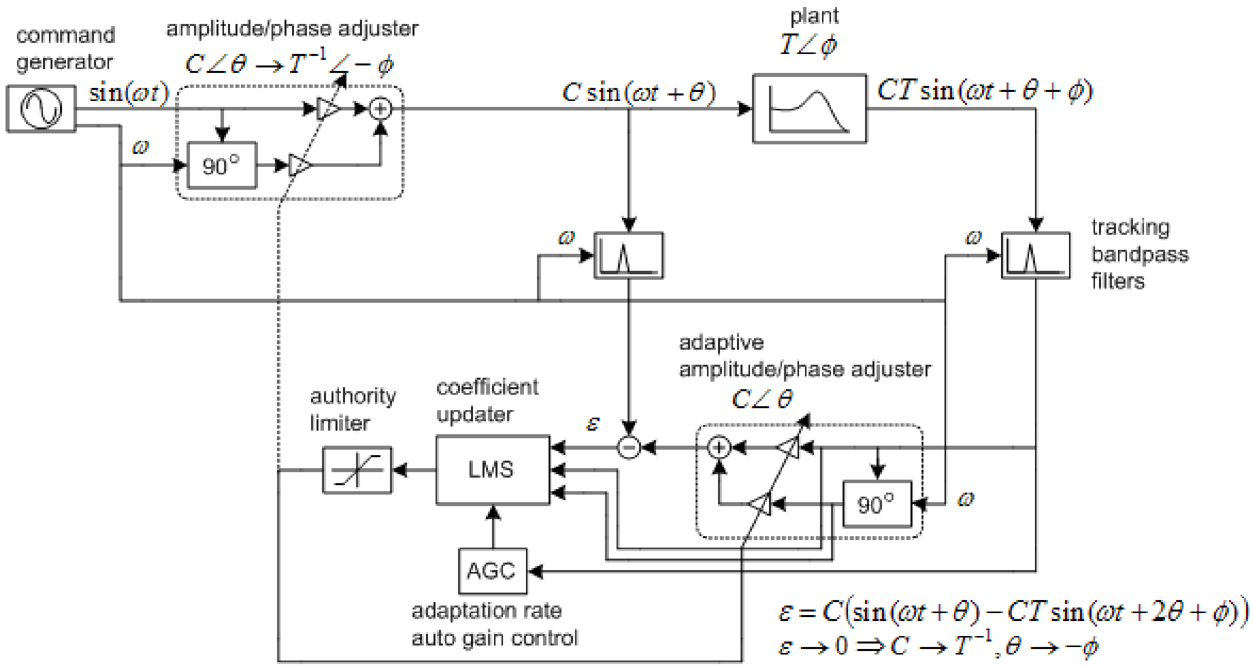
How APC Works

Amplitude/Phase Control (APC) is a control technique that eliminates amplitude and phase discrepancy between command and response when the command waveform is sinusoidal. This discrepancy arises from dynamics of the fixed-gain controller, actuator, fixture, and test specimen combination hereafter called the *plant*. Plant dynamics cause a sine command input to emerge at the plant output scaled in amplitude by a gain T and shifted in phase by angle ϕ (notationally, $T\angle\phi$). APC corrects this amplitude and phase discrepancy by preceding the plant input with a compensator network that scales the command amplitude by gain T^{-1} and shifts the phase by angle $-\phi$, resulting in an overall gain of $T^{-1} * T = 1$ and an overall phase shift of $-\phi + \phi = 0$. This is shown schematically below:



The inverse plant gain T^{-1} and phase shift $-\phi$ is not known in advance, so it is computed online by estimating the plant input with an inverse model driven by the plant output, comparing the estimated input with the actual input to develop an input error signal, and updating the inverse model in such a way as to drive the input error to zero. Once the input error is driven to zero, the inverse model gain and phase becomes $T^{-1}\angle-\phi$, which is copied to the inverse compensator placed between the command generator output and the plant input.

A more detailed view of the internal structure of APC is shown below:



Both inverse model and inverse compensators are amplitude/phase adjusting networks that implement the trigonometric identity

$$A\sin(\omega t) + B\cos(\omega t) = C\sin(\omega t + \phi),$$

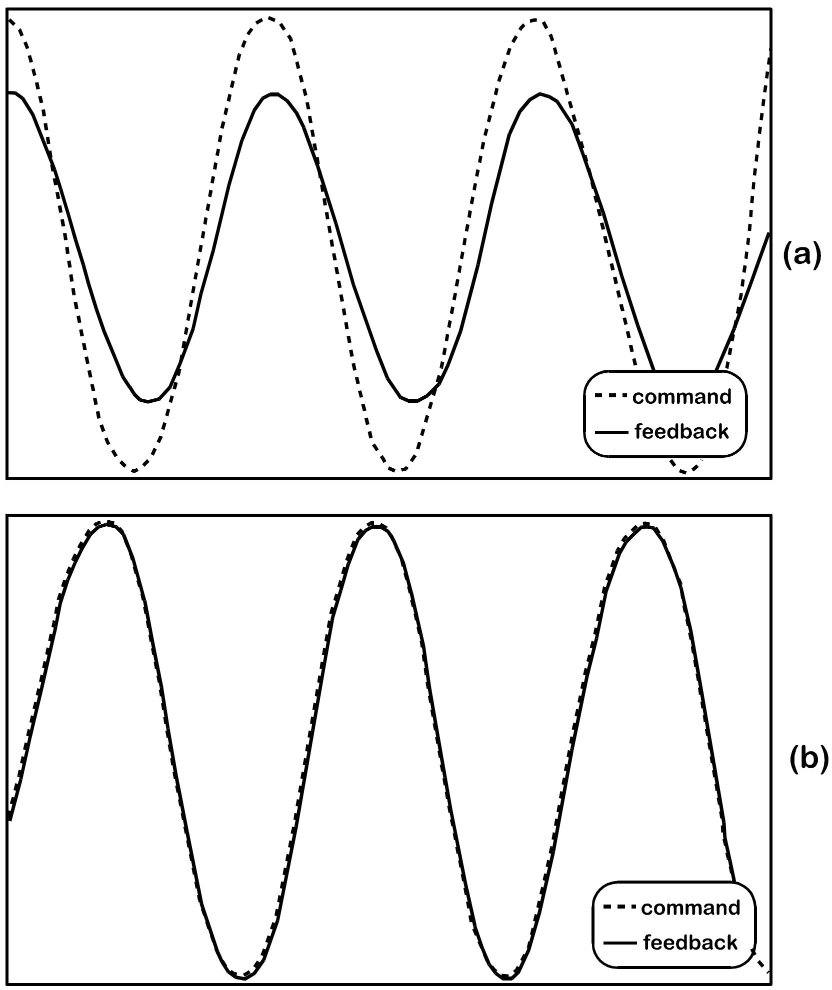
which states that by suitable choice of coefficients A and B, a sinusoid of any amplitude C and and any phase ϕ can be obtained. In APC, these coefficients are modified using the Least Mean Square (LMS) algorithm in such a way as to drive the input error ε to zero. It is beyond the scope of this document to discuss specifics about the LMS algorithm; there are many good digital signal processing textbooks available on this topic.

Note in the diagram above that both the plant input and output signals are filtered by narrowband bandpass filters. These allow APC to filter out harmonic frequency components that arise due to plant nonlinearities and focus instead on the fundamental frequency. The center frequencies of these bandpass filters are varied according to the current command generator frequency, allowing APC to work with sine sweep commands. This frequency is also used to update the quadrature (90°) phase shifters. Because APC needs current frequency information, you must use the built-in sine and sine sweep function generators. You cannot use an external sine generator or a sine time history file with APC because these command sources do not provide current frequency information.

Example

Before and After

The following figure shows the typical "before and after" responses of the system. In (a), there is a substantial mismatch between command and feedback with the APC switched off; in figure (b), the APC has been switched on and has completely removed amplitude and phase errors so that the feedback lies on top of the command.



Adaptive Harmonic Cancellers (AHC)

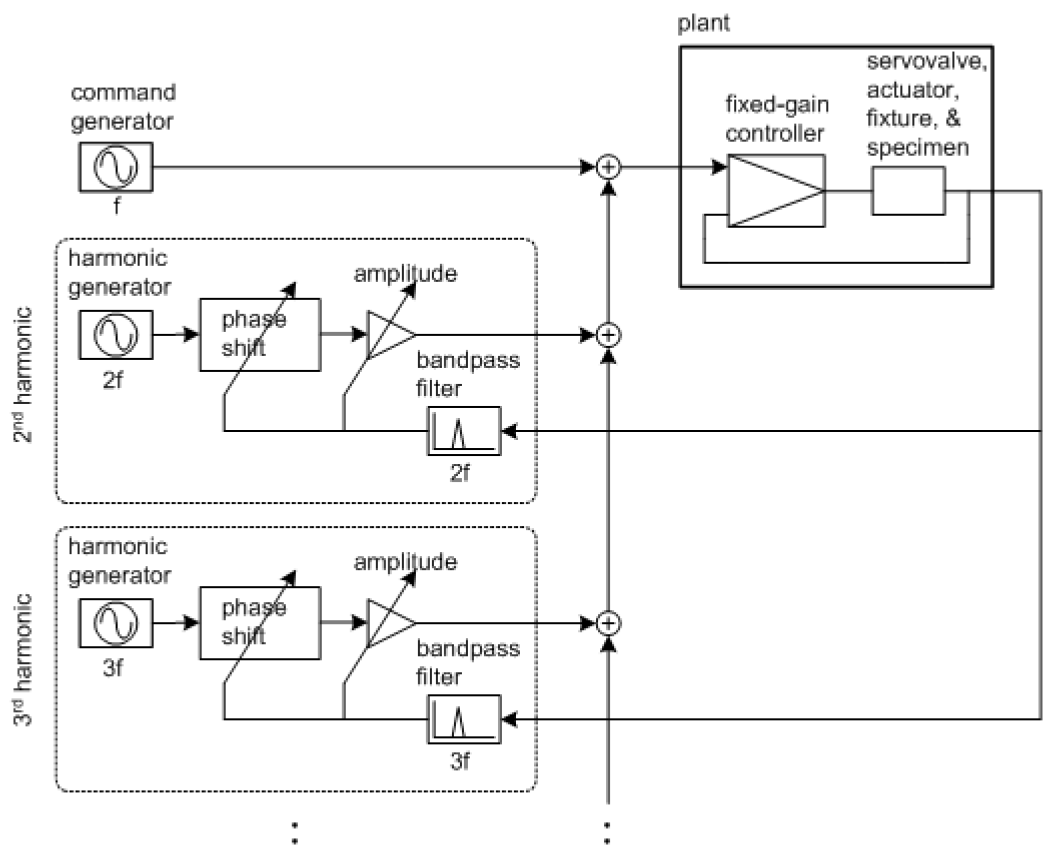
When nonlinearities are present in a feedback control system, spurious harmonics appear in the feedback even when the command is a simple sinusoid. This is especially true of servohydraulic seismic systems due to servovalve orifice nonlinearity. One way to reduce harmonic distortion is to increase the controller feedback gain. This tends to linearize the nonlinearity, but gain can be increased only so far before stability is compromised. Another way to reduce harmonic distortion is to iterate it out by playing the command waveform repeatedly, noting that the response, and updating the system drive waveform using the system inverse frequency response function. This method is quite effective, but can be very time consuming and requires a significant level of user interaction and sophistication. A new approach, inspired by active noise control technology, is to add harmonics to the controller command waveform with just the right phase and amplitude to cancel the harmonics at the system output. This technique is called "Adaptive Harmonic Cancellation" (AHC).

Adaptive Harmonic Cancellation (AHC) greatly reduces harmonic distortion of the response of a control system driven by a sinusoidal command. It measures the harmonic distortion directly and adapts in realtime the canceling waveform that it applies to the control system input.

AHC is optimized to work with sinusoidal command waveforms (both fixed and swept frequency). To improve the fidelity of the system's response to a sine command, AHC can be augmented with Amplitude/Phase Control (APC). APC and AHC complement each other: APC enhances the fundamental frequency component of the system response while AHC cancels the harmonics.

How AHC works

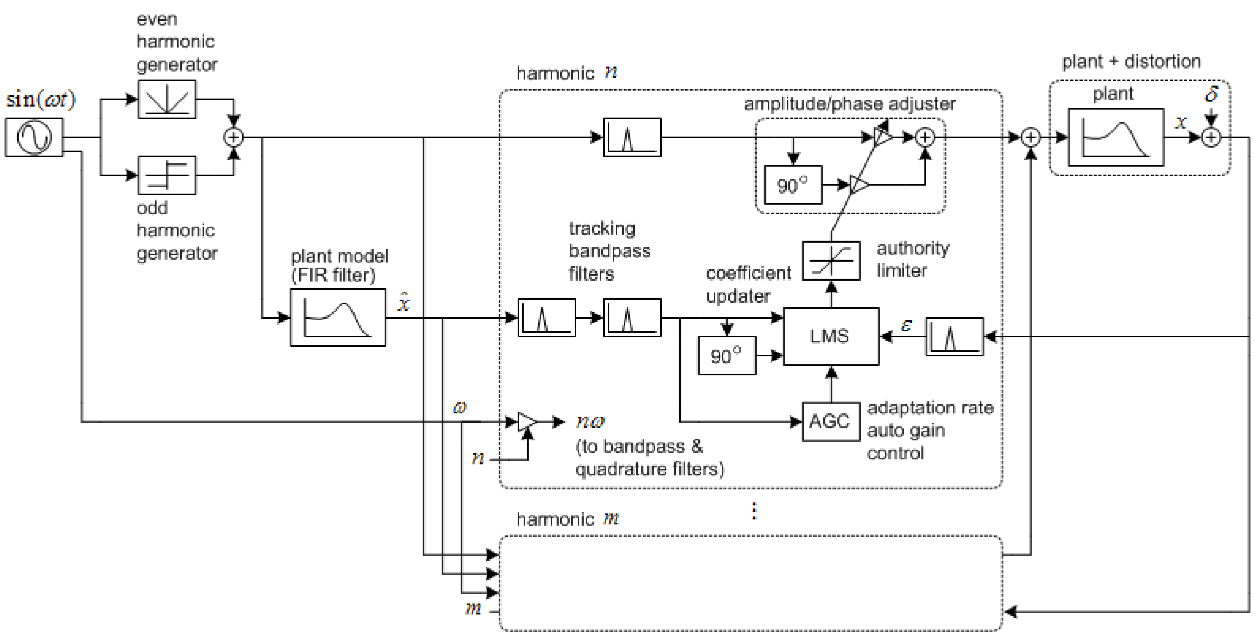
When a control system consisting of a fixed-gain controller, actuator, fixture, and test specimen (hereafter called the *plant)* is driven by a sinusoidal command, nonlinearity in the plant will cause frequency components at multiples of the command frequency to spontaneously appear at the plant output. These harmonics cause unwanted discrepancies between command and feedback. Eliminating a harmonic is conceptually straightforward: simply add to the command a "cancelling signal" of the same frequency as the harmonic and with amplitude and phase such that what propagates through the plant and emerges at the output has the same amplitude but opposite polarity as the harmonic, thereby cancelling it. In order for this scheme to work properly, the cancelling signal must have the correct amplitude and phase to a high degree of precision that can only be obtained by adapting them according to online measurement of the harmonic.



As shown in the diagram above, AHC consists of a parallel network of cancellers, each dedicated to a single harmonic. A bandpass filter tuned to the harmonic frequency extracts the harmonic from the plant output.

The extracted harmonic is used as an error signal to adapt the amplitude and phase of the cancelling signal which is then added to the command input of the plant. Once the harmonic is cancelled, the adaptation error is zero and the amplitude and phase are constant at appropriate values.

A more detailed view of the internal structure of AHC is shown below:



The amplitude/phase adjusting network in each harmonic canceller is based on the trigonometric identity which states that by suitable choice of coefficients A and B, a sinusoid of any amplitude C and and any phase ϕ can be obtained. In AHC, these coefficients are modified using the Least Mean Square (LMS) algorithm in such a way as to drive the response error ε to zero. It is beyond the scope of this document to discuss specifics about the LMS algorithm; there are many good digital signal processing textbooks available on this topic.

$$A\sin(\omega t) + B\cos(\omega t) = C\sin(\omega t + \phi),$$

Note in the diagram the presence of a model of the plant, which give the LMS algorithm critical phase information that it needs to adapt canceller coefficients. The transfer function of this plant model must be measured online during a training procedure prior to cancelling harmonics.

Also note in the diagram above that the harmonic generator output and the plant response are filtered by narrowband bandpass filters. These extract content from the signal only at the harmonic frequency. The center frequencies of these bandpass filters are varied according to a multiple of the current command generator frequency, allowing AHC to work with sine sweep command waveforms. This frequency is also used to update the quadrature ($90°$) phase shifters. Because AHC needs current frequency information, you must use the built-in sine and sine sweep function generators. You cannot use an external sine generator or a sine time history file with AHC because these command sources do not provide current frequency information.

Adaptive Inverse Control (AIC)

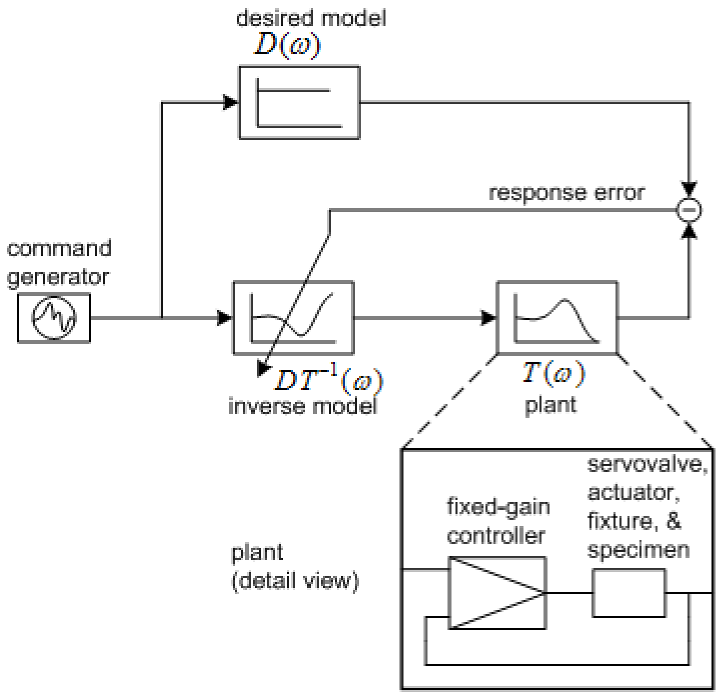
Adaptive Inverse Control (AIC) is a control compensation technique that augments a fixed-gain controller to correct for closed-loop gain and phase irregularities in order to improve control fidelity. In addition, in multichannel control systems with cross-coupled dynamics, it greatly reduces cross-coupling 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:

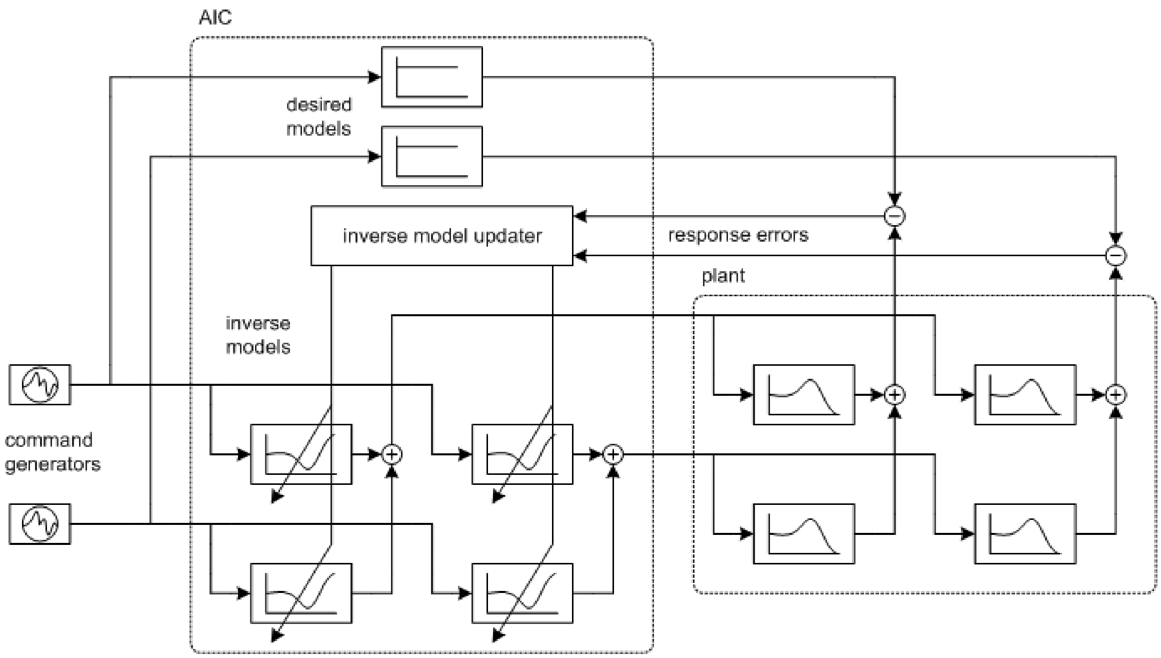


Ideally we would like the transfer function between command and plant response to be $D(\omega)$ rather than $T(\omega)$, which represents the dynamics of the fixed-gain controller, actuator, fixture, and test specimen combination hereafter called the *plant*. When AIC's inverse model is placed between 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:

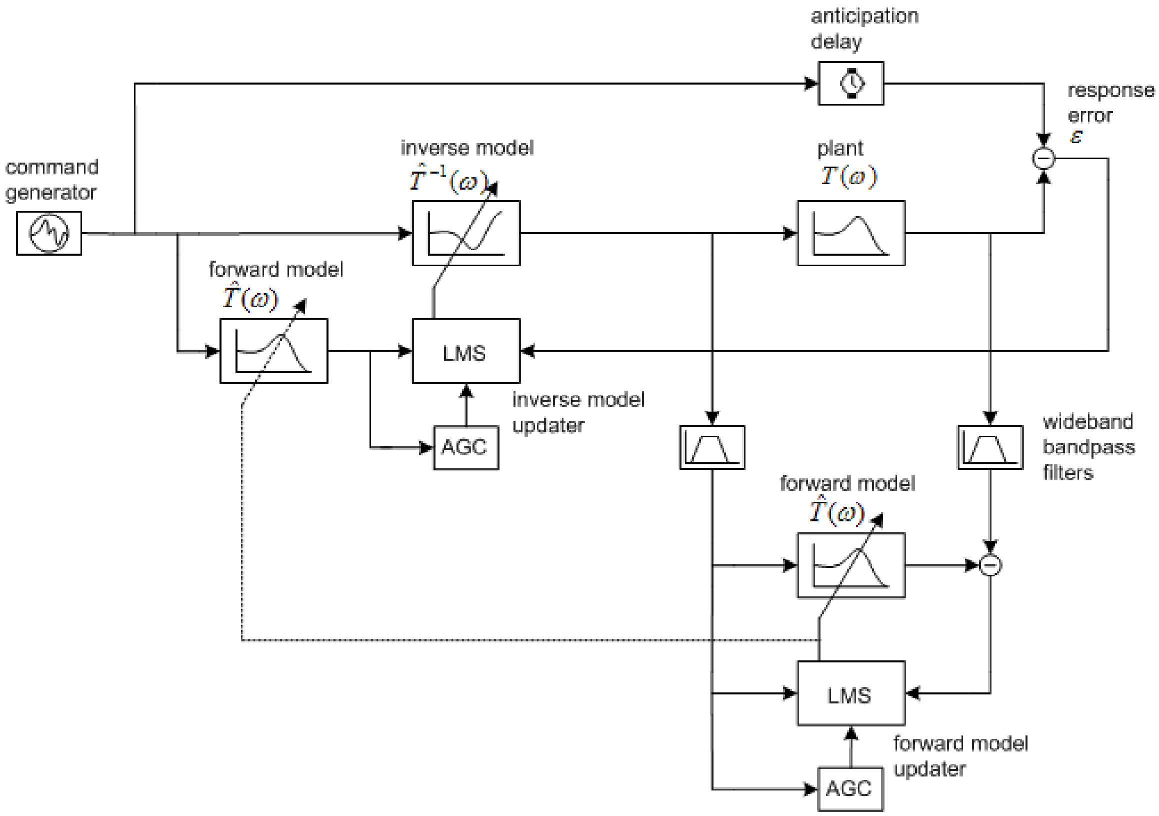


Instead of a single transfer function $T(\omega)$, the plant now consists of a matrix of transfer functions that represent the interaction between every combination of input and output. Likewise, AIC has a matrix of inverse models. The diagonal terms of the matrix correspond to the main interaction between 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.

On-line Iteration (OLI)

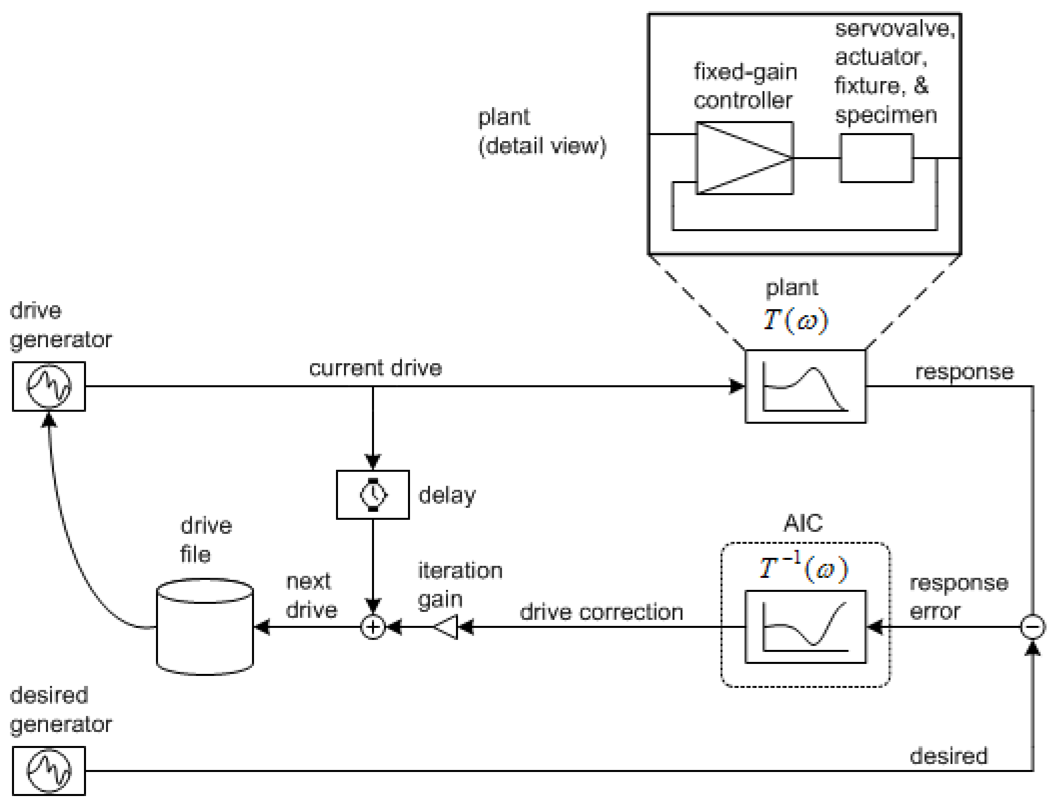
Online Iteration (OLI) is a control technique that repeatedly modifies the command input to a control system on an individual sample-by-sample basis until the control system response is almost a perfect replica of the original desired command.

OLI is optimized to work with non-sinusoidal command waveforms and significantly nonlinear systems. If the command waveform is a pure sine wave, Adaptive Harmonic Cancellation (AHC) works better and is easier to use. If the system does not have significant nonlinearities, use Adaptive Inverse Control (AIC) instead.

How OLI works

The focus of OLI is two time history files, the "desired" file and the "drive" file. The desired file is an unchanging file that contains the time history that you want to reproduce on the test system. The drive file is a time history file that is modified every time it is played out in such a way as to cause the system response to eventually match the desired time history. The process of repeatedly playing out the desired and drive files while updating the drive file is called "iteration".

OLI is shown schematically in the diagram below:



In the diagram above, the desired time history file and the drive time history file are played out simultaneously through their respective waveform generators. The drive is played directly into the *plant*, which is the term used hereafter to refer to the dynamics of the fixed-gain controller, actuator, fixture, and test specimen combination. Simultaneously, the desired is played out and compared to the plant response to develop a response error. A drive correction is computed by running the response error through a filter that approximates the inverse transfer function of the plant. This drive correction represents a best linear estimate of the amount of drive error that gave rise to the response error. A fraction of the drive correction specified by the "iteration gain" is added to the current drive waveform (delayed to account for plant and processing delays) to form the drive for the next iteration cycle and the result is stored in a disk file. The iteration gain, whose value ranges from zero to one, determines the rate at which the response converges to the desired and is chosen according to the amount of nonlinearity in the plant. For a very nonlinear plant, the iteration gain must be small and the number of iterations large for the iteration process to converge. For a predominantly linear plant, an iteration gain of nearly one is possible without divergence, in which case only two or three iterations are required.

Note in the diagram that OLI requires knowledge of the inverse transfer function of the plant in order to compute a drive correction. This inverse transfer function is provided by the Adaptive Inverse Controller (AIC), appropriately rewired to serve in this role, and is determined by a training process prior to running OLI; refer to the document "How To Use AIC" for details.

Summary of AIC and OLI

AIC is an effective digital control technique for improving tracking accuracy in mainly linear servohydraulic test systems. When nonlinearities are significant, *on-line iteration* (OLI) works with AIC to eliminate tracking errors.

For more information on the Adaptive Inverse Controllers panel, see “Adaptive Inverse Controllers” in Chapter 5.

For more information on the Online Iteration panel, see “Online Iteration” in Chapter 5.

Section 4

Introduction to Control Software

Overview

This section contains information on the following topics:

- Setting up your hard disk
- Using the 469D Digital Seismic Table Controller software
- Using the software control panels

This manual does not describe standard PC procedures. Before using the system, you should be familiar with your PC operating system. Of particular importance are the procedures relating to selecting and moving files, opening and closing files, moving windows, and using file folders. For information about the PC, refer to the PC documentation provided with your system.

Setting Up Your Hard Disk

To run the 469D Digital Seismic Table Controller software, the application and support files must be installed on your PC.

NOTE *The application and support files listed below have already been installed on the computer system by MTS during installation. The following procedure for installing the programs should only be done in the event of a hard disk failure or other event that corrupts the disk or software files.*

Required Files

The files named *469D.exe, Settings.set, Calibration.cal and Table.dat* and the folder *bin* must be installed on your hard drive in the folder, "c:\469D". These files contain the 469D Digital Seismic Table Controller application software, default setting parameters, calibration parameters and system specific data for your system.

Backup Copies

MTS recommends that you make backup copies of the 469D Digital Seismic Table Controller application and support files. Keep this backup copy in a safe place to ensure that, if a file is corrupted during operation, you can restore the file and operate your system.

Using the 469D Digital Seismic Table Controller Software

This section describes how to start the control software, load calibration parameters, save and restore system settings files, and quit the control software.

Starting the Control Software

The 469D Digital Seismic Table Controller application contains the control software, calibration data, and the default setting parameters for your system. Opening this application will load the calibration parameters and open the 469D Digital Seismic Table Controller Main Panel and the default Settings file.

NOTE *After you use the control software to set up the system for a test, you can save the system settings in a new file. During system startup, the system automatically opens the default Settings file. You can select and use a different "settings" file after system startup.*

The 469D Digital Seismic Table Controller main panel is the control center of this application. You can use the menus of this panel to access all options for calibrating, configuring, setting up tests, and displaying data. You can also use the controls and displays of this panel to set or check functions, to enable adaptive control, and to run a test.

Calibration File

The hardware dependant parameters for the system are stored in a calibration file that is automatically loaded when the application is opened. There is only one calibration file for the system and it must be called *Calibration.cal*. This file contains calibration data for the A/D and D/A Converters, AC and DC Conditioners, and Valve Drivers. Hardware is calibrated using the panels found under the Calibration menu and new parameters are saved using the Save Calibration option. If needed, you can restore the parameters stored in the calibration file by selecting the Restore Calibration option. This is useful if you change parameters on any of the calibration panels and wish to return to the original values.

Saving and Restoring System Settings Files

When you set up your system for a test, you will complete a number of procedures defining the system test settings. These settings include servo control loop adjustments, limit detector settings, function generator settings, and adaptive control settings.

NOTE *When you save a system settings file, use the* ***Save Settings*** *option from the File menu on the 469D Digital Seismic Table Controller Main Panel.*

You can save these settings files and use them when running different types of tests. In this way, you can eliminate the need for re-defining the system parameters when running a different type of test.

You can choose to save system settings for a test in the same file you are currently using to run the software or in a new file. When saving a settings file, you should name the file in a way that makes it easily identifiable.

To save system settings:

1. Select **Save Settings...** from the main panel File menu. When you select **Save Settings...**, the system will open a PC Save window.

2. To save system settings in the same file you are currently using:

   Using standard PC file procedures, select the folder containing the existing settings file. Do not change the file name.

   To save system settings in a new file:

   Using standard PC file procedures, select the folder that you want to save the new settings file in and change the file name.

3. Click the **OK** button to save the file in the selected folder (or click **Cancel** to cancel the procedure, close the save window, and return to the 469D Digital Seismic Table Controller Main Panel).

To restore a system settings file that has been saved:

1. Select **Restore Settings...** from the 469D Digital Seismic Table Controller Main Panel File menu. The system will open a PC Find window.

2. Using standard PC file procedures, select the file that contains the system settings that you want to use.

3. Click the **OK** button to restore the selected file (or click **Cancel** to cancel the procedure, close the find window, and return to the 469D Digital Seismic Table Controller Main Panel).

Changing Access Modes

To change the access mode, select **Change Access** from the main panel File menu and select the desired access level. The current access level will have an *.

The available access modes are:

Basic—The basic user can adjust variables on the main panel and run a test along with setting up the function generators and the data recorder, and using all the display panels. The basic user can only observe the calibration and configuration panels, the controller panels, the online iteration panel, and the limit detector panel.

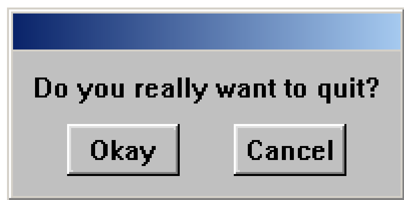
Extended—The extended user is responsible for setting up or designing a test and has access to all the parameters on all the panels.

Service—For MTS service personnel only.

Quitting the Control Software

To ensure you do not accidentally close the control software application, the close box on the 469D Digital Seismic Table Controller Main Panel is not functional. To quit the control software, complete the following steps:

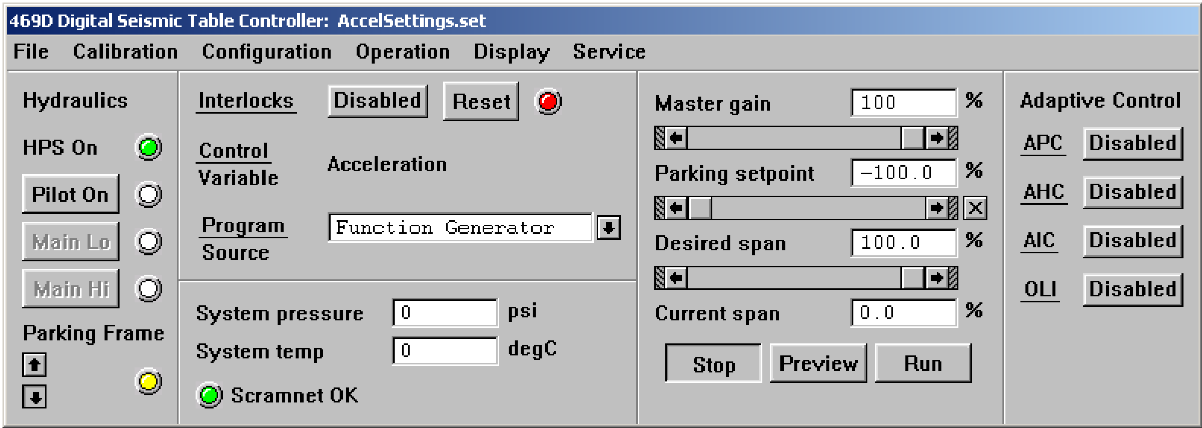
1. Select **Quit** from the File menu on the 469D Digital Seismic Table Controller Main Panel. When you select **Quit**, the system will open the following window:



2. Select **OK** to quit or **Cancel** to return to the control software without quitting.

NOTE — *After you have selected **Okay** to **Quit**, you must wait 45 seconds before restarting the software. This allows the software to properly prepare for startup.*

The 469D Digital Seismic Table Controller Main Panel



As previously described, the 469D Main Panel contains a menu bar, system controls, and indicators. It is opened automatically when you start the control software. You use the menus on the 469D Main Panel to access option panels used to set up the system. The following menus are included on the 469D main panel:

- File
- Calibration
- Configuration
- Operation
- Display

The main panel also has system controls and indicators which allow the user to do the following:

- Enable and monitor hydraulics
- Reset Interlocks
- Enable/disable limits
- Monitor control variable
- Monitor program source
- Monitor system pressure
- Set master gain, setpoint and span values
- Monitor current span
- Stop, preview, or run a test
- Enable or disable adaptive control

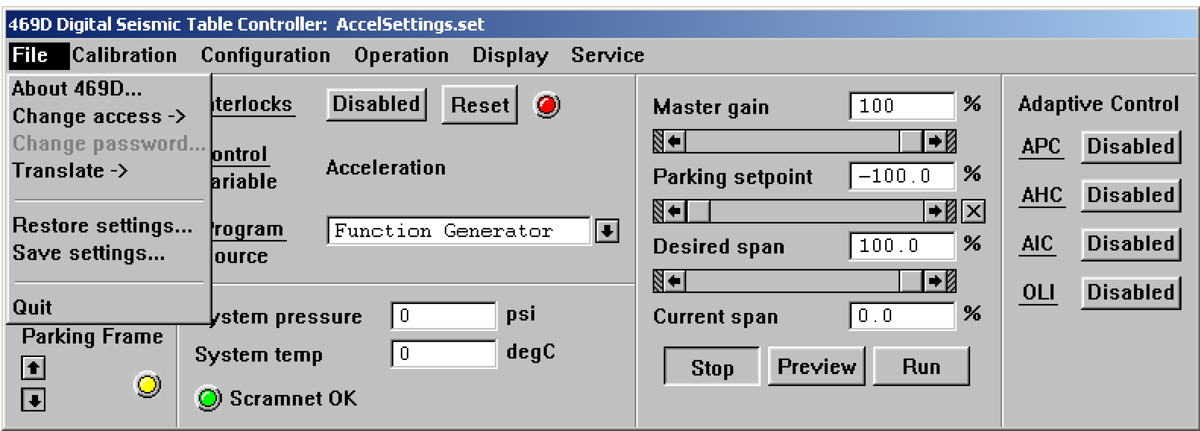
Refer to the Main Panel in Section 5, *Control Panel Reference,* for more detailed information on how to use the main panel controls and indicators.

Main Panel Menus

The following figures illustrate the pulldown menus and corresponding option panels and commands available from the main panel. Option panels are used to set up a test. Each option panel contains a panel label, a close box, and controls and displays specific to the option panel.

Each main panel menu and corresponding commands and control panels are defined below. Refer to the following section, *Control Panel Reference*, for more detailed explanations on how to use each panel.

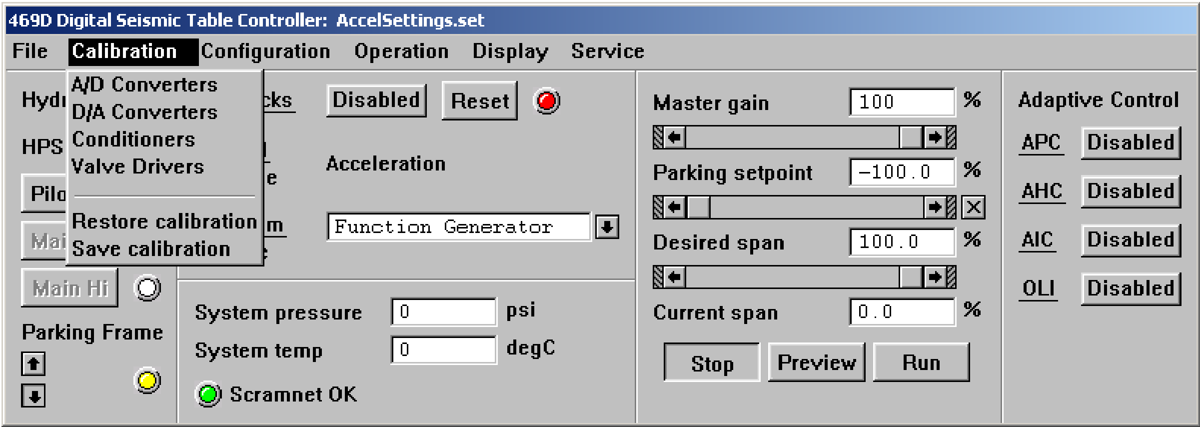
File



Use the commands on this menu to perform the following tasks (tasks marked with an asterisk (*) are available only to users with extended or service access privileges):

- **About 469D**-displays current software version and copy rights
- **Change Access**-change access level (Basic, Extended or Service)
- **Change Password**-create or change the password for access privileges*
- **Translate text to binary**-translates data files from text to MTS binary format. This can be used to translate a playout file. Refer to the Function Generator panel in Section 5 of this manual.
- **Restore settings**-restore Digital Seismic Table Controller settings from an existing disk file*
- **Save settings**-save Digital Seismic Table Controller settings to a disk file*
- **Quit**-quit from Digital Seismic Table Controller application

Calibration

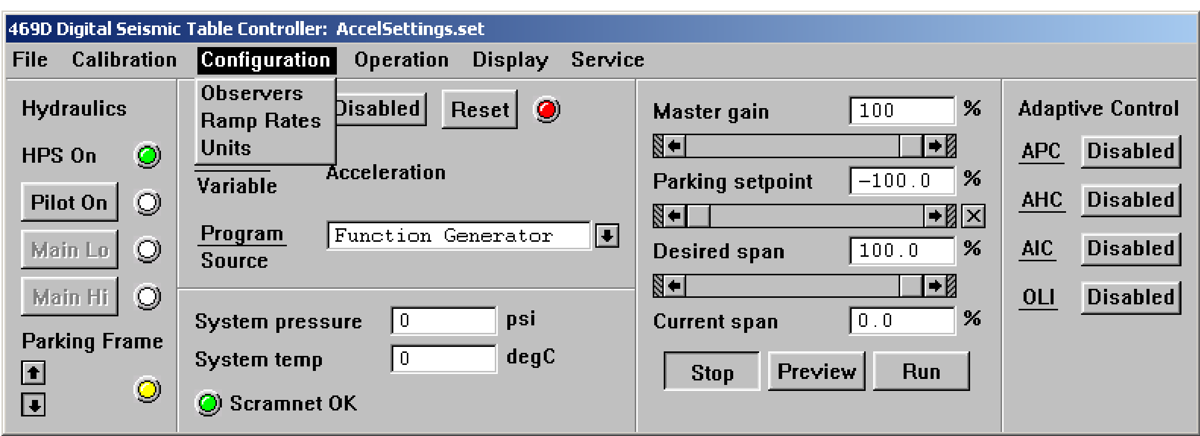


Use the commands on this menu to calibrate the following devices:

- Converters
- Conditioners
- Valve Drivers

Also use this menu to save/restore the calibration parameters to/from the calibration file.

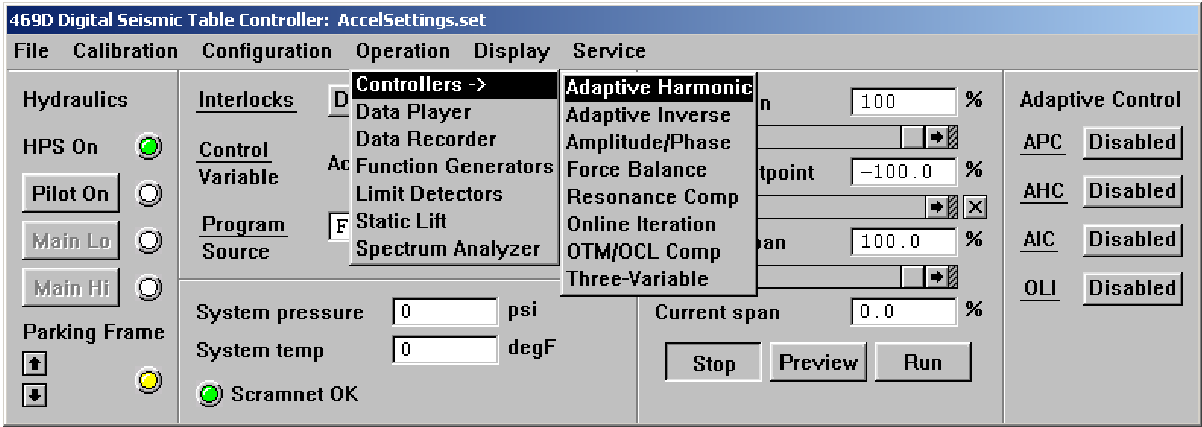
Configuration



Use the commands on this menu to configure the following:

- Observers
- Ramp Rates
- Units

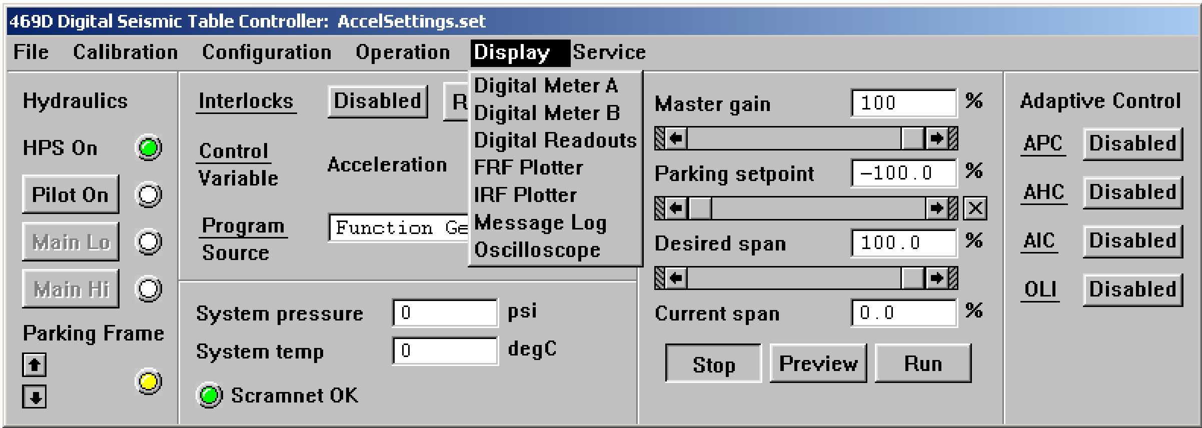
Operation



Use the commands on this menu to perform the following tasks:

- **Controllers-**set parameters for both Three Variable Control and adaptive controllers. A side menu allows you to set parameters for:
  - – Adaptive harmonic cancellers
  - – Adaptive inverse control
  - – Amplitude/phase control
  - – Force balance
  - – Resonance compensators
  - – Online iteration
  - – OTM/OCL comp
  - – Three-variable controller
- **Data Player–**select a time history file as the program source
- **Data Recorder-**set up data acquisition to a file
- **Function Generators-**set parameters for function generators
- **Limit Detectors-**setup limit detectors
- **Static Lift –** run and monitor the static support system
- **Spectrum Analyzer-**set parameters for spectrum analyzer

Display



Use the commands on this menu to display data on the following types of panels:

- **Digital Meters A and B**-to read the present value of a signal and to monitor the maximum/ minimum values, or the peak/valley values over time
- **Digital Readouts**-to display the present value of one or more signals
- **FRF Plotter**-to plot the FRF (frequency response function) to show frequency responses computed by the Spectrum Analyzer
- **IRF Plotter**- to plot the IRF (impulse response function) to show the impulse response of the adaptive controller or to display the forward IRF determined by the system identifier
- **Message Log-**display current messages in the message log
- **Oscilloscope-**display oscilloscope traces of various signals

Selecting an Option from a Main Panel Menu

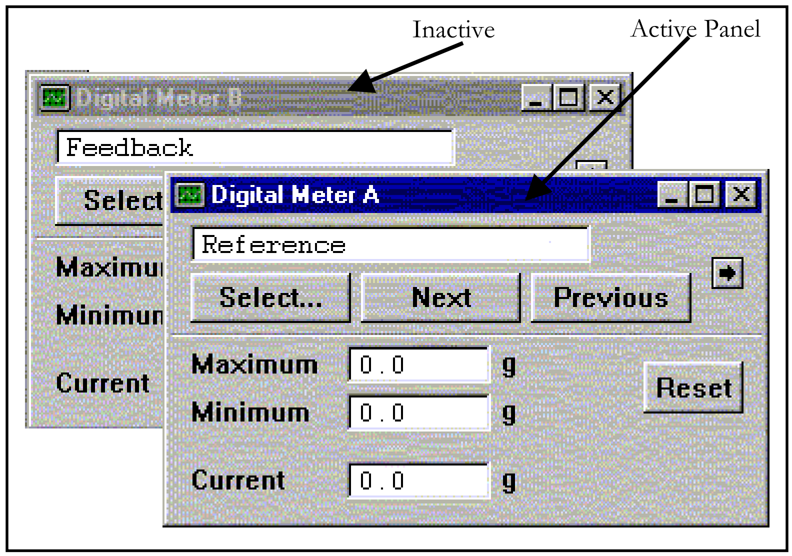
To access a control panel from a main panel menu, complete the following steps:

1. Click on the menu title associated with the option you want to access.
2. Move the mouse to highlight the option you want to access.
3. When the option is highlighted, click the mouse button again.

When you release the mouse button, the panel associated with the option will open automatically and become the active panel.

Making a Control Panel Active

Although more than one control panel can be open at the same time, only one panel can be *active* at a time. You can enter information and use the controls only on the active panel.



When you first open a panel, it automatically becomes the active panel and you can use the panel's controls. To make a different panel active, click anywhere on that panel. When you do this, the panel will be redrawn on the top of the other panel(s) and become active.

NOTE: *When switching from one panel to another, the first mouse click only activates the panel. The first click is not directed at a control,*

Closing a Control Panel

Each control panel has a close box in its upper right-hand corner. To close a control panel, click on the close box when the panel is active.

Using the Software Panel Controls

The control panels contain a variety of controls that you use to make selections and enter test parameters. You use the controls by moving and clicking the mouse.

The panel controls are illustrated and described in the following table.

Table 1-1. Software Panel Control Descriptions

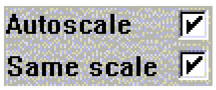
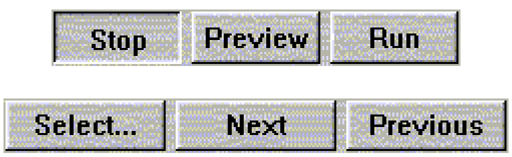
CONTROL OR DISPLAY	DESCRIPTION
Check Boxes 	*Check boxes* are used when you can select any option in a set of options. A selected check box shows a check mark. Click on a check box to select or deselect its option.
Function Buttons 	Click a *function button* to complete the function associated with the button. Some of the most common function buttons are illustrated at the left. The Stop, Preview and Run buttons are used to system. The Select..., Next, and Previous buttons are used to select a channel or signal for which you want to enter information. Any function button that has an ellipsis (...) following its label accesses a secondary panel. For example, the Select... button shown at the left accesses a selection panel, from which you select a channel or signal.
Indicators 	An *Indicator* is a small circle that identifies a specific condition in the test system. The condition, identified by the label associated with the indicator, exists if the indicator is filled (like the Tracking indicator shown on the left). The indicators in the control panels are set by the control electronics. Refer to the appropriate description in Section 5, *Control Panel Reference*, for more information about a specific indicator and, if applicable, for instructions on clearing an indicator.

Table 1-1 (con't). Software Panel Control Descriptions

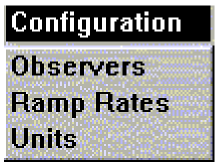
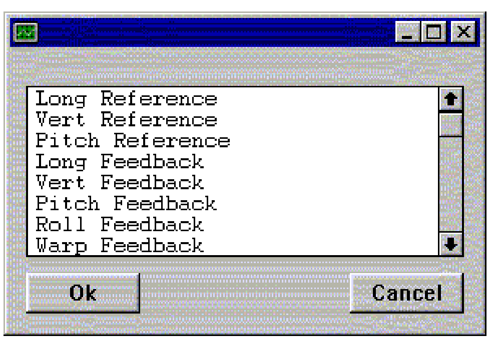
CONTROL OR DISPLAY	DESCRIPTION
Pulldown Menus 	A pulldown menu is used to select one option from a list of options. To display the selections on a pulldown menu, click and hold on the pulldown menu field until the menu appears. Move the mouse to highlight the option you want to select and then release the mouse button.
Radio Buttons 	*Radio buttons* are used when you can select only one option in a set of options. The selected radio button is the one with the darkened center. Click on a radio button to select an option. When you select one of the radio buttons in the set, the other button(s) in that set are automatically deselected.
Scroll Bars  	A *scroll bar* can be used to view all available selections in a selection box or all available messages in the Message Log. To view selections or messages, use the scroll bar in one of the following ways: • Click and hold or click repeatedly on the scroll bar arrows to "scroll" through the selection/message list. • Click and then drag the box in the scroll bar to move through the selection/message list. • Click on the bar outside of the box to "jump" through the available selections/messages.

Table 1-1 (con't). Software Panel Control Descriptions

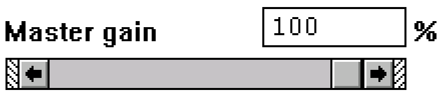
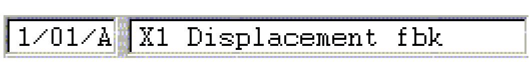
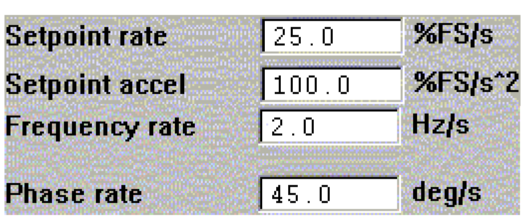
CONTROL OR DISPLAY	DESCRIPTION
Slide Bars 	A *slide bar* is used to enter numeric values in the system. Each slide bar is associated with a specific signal or value, which is identified by the label on the slide bar. The current value is shown in a text box above the bar. The units associated with the signal or value are also identified on the slide bar. Change the value identified on a slide bar in one of the following ways: • Click and hold or click repeatedly on the slide bar arrows to "scroll" through the range of values. • Click and hold, and then drag the box in the slide bar to change the value. • Click on the arrow on either side of the box to "jump" through the range of values. • Highlight the text box, type in the desired value and then press the return key on the keyboard. A quick double click highlights existing text in the entire box. Typing then replaces the box contents. Each slide bar has a defined range. For example, the range of the Master gain slide bar is 0 to 100%. You can change the range associated with a slide bar by clicking on one of the small striped rectangles at the end of the bar. After clicking on the rectangle, type the value desired and press the return key to enter the new range value in the system. To cancel without entering a new range value, click on the striped rectangle again. One mouse click on the slide bar moves the current value of the adjustment by 1% of the full range. *(Slide Bars continued on next page)*

Table 1-1 (con't). Software Panel Control Descriptions

CONTROL OR DISPLAY	**DESCRIPTION**
Slide Bars (continued)	This also affects scrolling resolution. To increase the scrolling resolution, reduce the range. **⚠ WARNING** If the range is large, small movements of the slide bar can cause large changes in the control loop. Unexpected actuator action could result. Unexpected actuator action can cause injury to personnel or damage to equipment. **To avoid injury or damage, use a small enough range to ensure that no major control system motions occur.**
Status Buttons (with indicator) 	A status button is a function button that is linked to an indicator. The function is selected by the button, and the status of the function is identified by the indicator. For example, the HPS On status button changes the state of the hydraulic power supplies.
Text boxes  	A *text box* contains current selections, selection information, or alphanumeric data. Some text boxes are editable and some are not editable. To change the entry in a *selection text box* you have to use functions buttons associated with the field (for example, a Select... button). The name of the entry can be changed by selecting the text in the box, typing the desired name over it, and then pressing the return key. (Double clicking on the text will select all of it). A *display text box* is not editable, but is updated whenever you change the associated selection. An example of this type of text box is the Chan text box shown on the left. An *alphanumeric text box* is used to enter data into the system. Examples of this type of text box are the text boxes shown on the left. To change the data in a text box, select the existing text, type the desired information over it, and then press the return key.

Section 5

Control Panel Reference

Overview

This section contains alphabetically arranged descriptions for each control panel in the 469D Digital Seismic Table Controller software.

⚠ WARNING

For most options, a control panel is automatically opened when you select the option. These control panels display current settings.

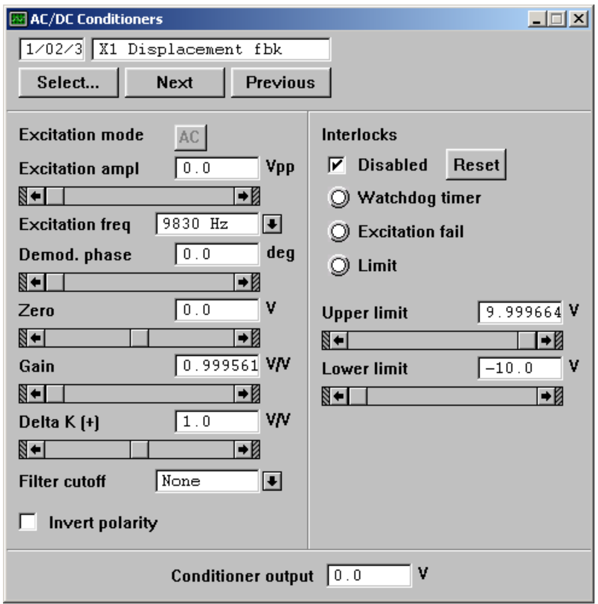
Before you change a displayed setting, know the effect the change will have on the system. Refer to *Section 6, Operation*, before adjusting any value or attempting to operate the system.

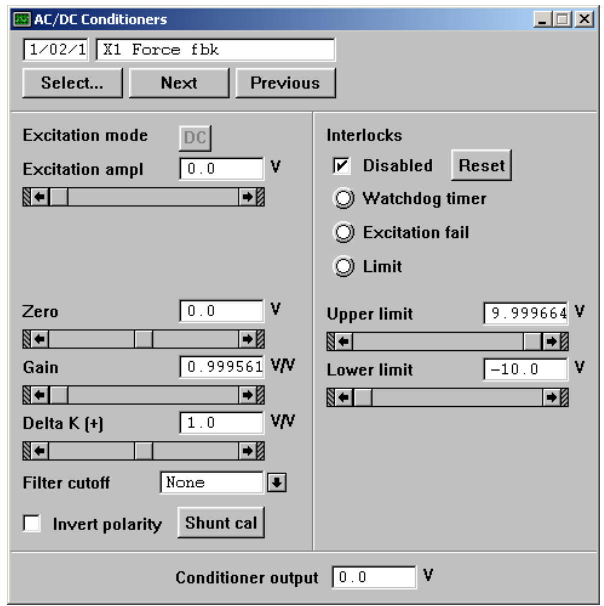
The following table identifies each panel described in this section, as well as its corresponding option name and menu location. Refer to Section 4, *Introduction to Control Software*, for information on how to select these menu options

PANEL NAME	MENU	MENU OPTION
AC/DC Conditioners	Calibration	Conditioners
A/D Converters	Calibration	A/D Converters
Adaptive Harmonic Cancellers	Operation	Controllers: Adaptive Harmonic
Amplitude/Phase Controllers	Operation	Controllers: Amplitude/Phase
D/A Converters	Calibration	D/A Converters
Data Player	Operation	Data Player
Data Recorder	Operation	Data Recorder
Digital Meter A or B	Display	Digital Meter A Digital Meter B
Digital Readouts	Display	Digital Readouts
Force Balance Controllers	Operation	Controllers: Force Balance
Frequency Response Function Plotter	View	FRF Plotter
Function Generator	Operation	Function Generators

PANEL NAME	MENU	MENU OPTION
Impulse Response Function Plotter	Display	IRF Plotter
Limit Detectors	Operation	Limit Detectors
Main Panel	--	--
Message Log	Display	Message Log
Multichannel AIC	Operation	Controllers: Adaptive Inverse
Observers	Configuration	Observers
Online Iteration	Operation	Controllers: Online Iteration
Oscilloscope	Display	Oscilloscope
Overturning Moment/Off Center Load Compensators	Operation	Controllers: OTM/OCL Comp
Ramp Rates	Configuration	Ramp Rates
Resonance Compensator	Operation	Controllers: Resonance Comp
Spectrum Analyzer	Operation	Spectrum Analyzer
Static Lift	Operation	Static Lift
Three-Variable Controller	Operation	Controllers: Three-Variable
Units	Configuration	Units
Valve Drivers	Calibration	Valve Drivers

AC/DC Conditioners





Panel Description

The Conditioners panel allows you to perform the following tasks:

- Select a specific AC or DC conditioner
- Calibrate the conditioner to its associated transducer
- Select polarity of output
- Select filtering option
- Set hardware limits for the conditioner output (feedback)
- Identify whether an interlock has occurred
- Disable and/or reset interlocks

Access

Open the Conditioners panel by selecting the Conditioners option from the **Calibration** menu on the main panel.

When to Use the Panel

Use the Conditioners panel to calibrate a conditioner with its associated transducer and to identify and reset hardware interlocks. Whenever a transducer is replaced or moved, the associated conditioner should be calibrated. Hardware limits should be checked and reset before starting a test. In addition, MTS recommends verifying calibration values periodically.

AC/DC Conditioners (continued)

Control Descriptions

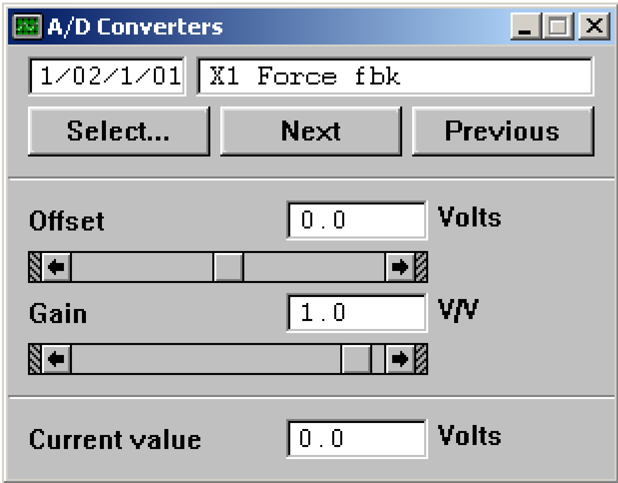
Control	Description
Cond text box	Shows the name of the currently selected conditioner. The adjacent conditioner ID box shows the slot number of the selected conditioner. Select a conditioner using the **Select...**, **Next**, or **Previous** buttons.
Select... button	Opens the conditioner selection panel, from which you can select a conditioner.
Next button	Selects the next conditioner in the selection panel list.
Previous button	Selects the preceding conditioner in the selection panel list.
Excitation mode pop-up	Displays the type of conditioner selected; AC or DC.
Excitation slide bar and text box	Sets the level of the excitation signal sent to the transducer. You can use the slide bar to set a value or you can enter it in the text box.
Demod. phase slide bar and text box	(Available for AC excitation mode only) Sets the demodulator phase of the AC conditioner output. You can use the slide bar to set a value or you can enter it in the text box.
Zero slide bar and text box	Sets the dc offset of the conditioner output. You can use the slide bar to set a value or you can enter it in the text box.
Gain slide bar and text box	Sets the total gain of the conditioner. You can use the slide bar to set a value or you can enter it in the text box.
Delta K (+) slide bar and text box	Sets the delta K(+) value for the conditioner. You can use the slide bar to set a value or you can enter it in the text box.
Filter cutoff pop-up menu	Select the desired output filter cutoff frequency.
Invert Polarity checkbox	Selects the polarity of the output signal. The choices are: Inverted or noninverted.
Shunt Cal button	(Available for DC excitation mode only) Closes the shunt calibration relay to complete a shunt calibration of the conditioner and displays the value in the Conditioner Output Value display.

AC/DC Conditioners (continued)

Control Descriptions (continued)

Control	Description
Interlocks	
Disabled check box	When checked, disables hardware interlocks for this channel.
Reset button	When pressed, resets the hardware interlocks for this channel.
Watchdog timer indicator	Indicates the state of the watchdog timer.
Excitation fail indicator	Shows whether excitation has failed. This detector is always enabled, both in hardware and software. Excitation failure causes a system interlock because it may indicate a broken, defective or missing conditioner cable.
Limit indicator	Indicates whether the conditioner output has gone outside of the limits set using the Upper and Lower Limit slide bars.
Upper Limit slide bar and text box	Sets the upper limit of the conditioner output. You can use the slide bar to set a value or you can enter it in the text box. If the conditioner output (feedback) has exceeded this limit, the Limit indicator is lit.
Lower Limit slide bar and text box	Sets the lower limit of the conditioner output. You can use the slide bar to set a value or you can enter it in the text box. If the conditioner output (feedback) has fallen below this limit, the Limit indicator is lit.
Conditioner output value text box	Shows the value of the signal output by the selected conditioner. Not editable.

A/D Converters



Panel Description

The A/D Converters panel allows you to perform the following tasks:

- Select a specific user analog-to-digital (A/D) converter
- Adjust the offset and gain for the selected converter
- View the current voltage output value at the selected converter

Access

Open the A/D Converters panel by selecting the A/D Converters option from the **Calibration** menu on the main panel.

When to Use the Panel

Use the A/D Converters to periodically calibrate the user A/D converters (or ADCs) in the system to ensure that the input and output voltages are balanced.

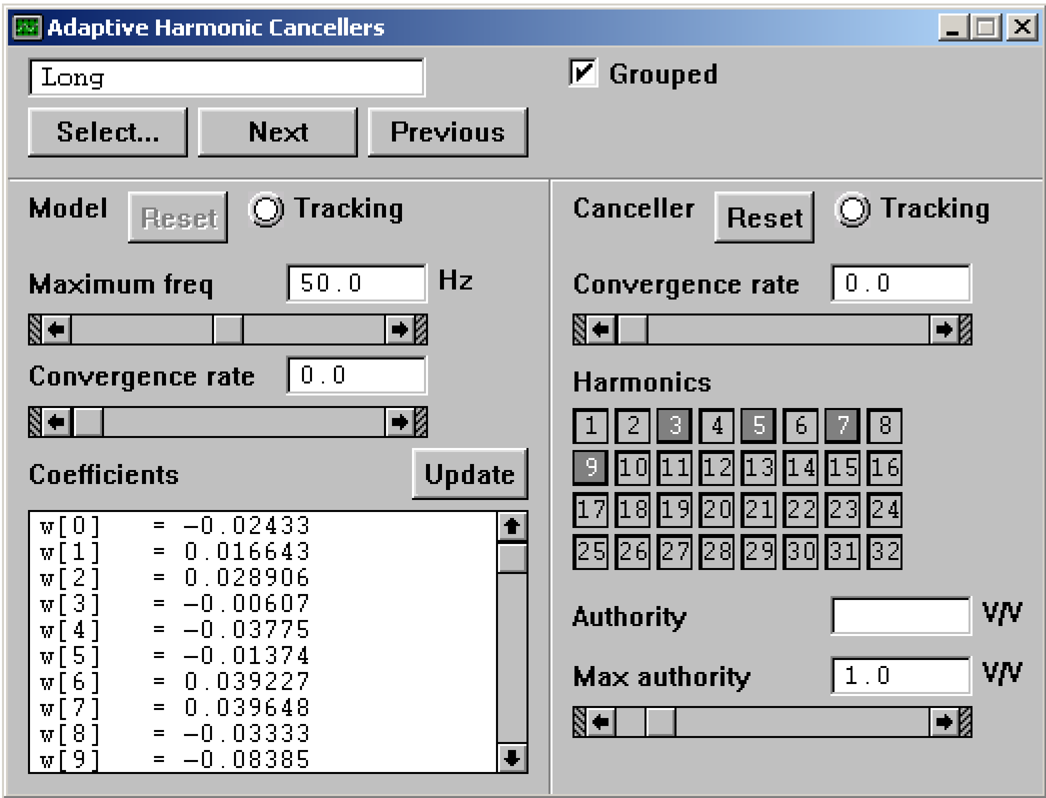
NOTE *Both offset and gain are saved in the Calibration file.*

A/D Converters (continued)

Control Descriptions

Control	Description
Conv text box	Shows the name of the currently selected channel. The adjacent channel ID box shows the number of the selected channel. Select a channel using the **Select...**, **Next**, or **Previous** buttons.
Select... button	Opens the converter selection panel, from which you can select a converter.
Next button	Selects the next converter in the selection panel list.
Previous button	Selects the preceding converter in the selection panel list.
Offset slide bar and text box	Adjusts the offset of the signal output by the converter. Use the **Offset** slide bar to set the A/D Converter for a current value of 0.00V. You can use the slide bar to set a value or you can enter it in the text box.
Gain slide bar and text box	Adjusts the gain of the signal output by the converter. Use the Gain adjustment to set the full-scale range of the A/D Converter. You can use the slide bar to set a value or you can enter it in the text box.
Current value text box	Shows the current value output by the selected converter. Not editable.

Adaptive Harmonic Cancellers



Panel Description

Adaptive Harmonic Cancellation (AHC) greatly reduces harmonic distortion of the response of a control system driven by a sinusoidal command. It measures the harmonic distortion directly and adapts in realtime the cancelling waveform that it applies to the control system input.

Access

Open the Adaptive Harmonic Canceller panel by selecting the **Controller** option from the **Operation** menu on the main panel, then dragging right to open the Controller submenu and selecting **Adaptive Harmonic**. You can also open this panel by clicking on the **AHC** icon on the Main panel.

When to Use the Panel

The Adaptive Harmonic Canceller panel allows you to setup adaptive harmonic canceller to reduce or cancel spurious harmonics in the feedback when programming sine waves. This approach will inject input harmonics into the controller command waveform with just the right phase and amplitude to cancel the desired feedback harmonics.

NOTE *Adaptive harmonic canceller function is turned on or off using the Adaptive Control button AHC on the main panel.*

Adaptive Harmonic Cancellers (continued)

Background Information

Because cancellation occurs at the system output by means of a signal at the system input, the phase response of the system must be known. The "control system model", an adaptive finite-impulse-response (FIR) filter, provides this information. Before cancellation is turned on, it must learn the system phase response by commanding the system with a random signal over the frequency range of operation.

During training, excite the system with a low level random signal using the Function Generator panel. The maximum frequency of the random signal should be entered into the Maximum Frequency text box on the Adaptive Harmonic Canceller panel.

Control Descriptions

Control	Description
Channel text box	Shows the name of the selected command channel. Select a channel using the **Select...**, **Next**, or **Previous** buttons.
Select... button	Opens the channel list box, from which you can select a channel.
Next button	Selects the next channel in the list.
Previous button	Selects the preceding channel in the list.
Grouped check box	When checked, this channel becomes part of the adaptive harmonic cancellation group. Changes to a parameter on any panel in the group affects all panels in the group. At the time that a channel is added to the group, its panel values will change to reflect the group values. It is recommended that all channels be grouped together for harmonic cancellation.
Model controls:	These controls are used during training.
Reset button	Resets coefficients to their initial state. Unless you are changing the test setup significantly, you do not need to reset coefficients.

Adaptive Harmonic Cancellers (continued)

Control Descriptions

<table>
<tr><th>Control</th><th>Description</th></tr>
<tr><td>Tracking indicator</td><td>Displays the current state of the model coefficient adaptation process. The tracking indicator is green if coefficients are adapting, white if not. The conditions for tracking are:
The AHC mode is set to Training.
The model convergence rate is nonzero.
The command waveform is not constant at zero or any other level.</td></tr>
<tr><td>Maximum Frequency slide bar and text box</td><td>Set the maximum frequency up to which AHC will cancel harmonics. This value should be the set to the maximum frequency used to train the model. AHC cannot cancel harmonics outside the range of frequencies in which it has been trained.

If the command waveform is a sine sweep, when a harmonic exceeds the maximum frequency, cancellation of that harmonic is automatically disabled. Once the harmonic frequency is within range again, cancellation of that harmonic is automatically reenabled.</td></tr>
<tr><td>Convergence rate slide bar and text box</td><td>Set the convergence rate of the model coefficient adaptation process. A value of zero means no adaptation; higher values increase the speed of the adaptation process at a cost of decreased model 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.

CAUTION

Setting the convergence rate too high will cause system instability.

Instability can result in uncontrolled actuator movement that can cause both equipment and specimen damage.

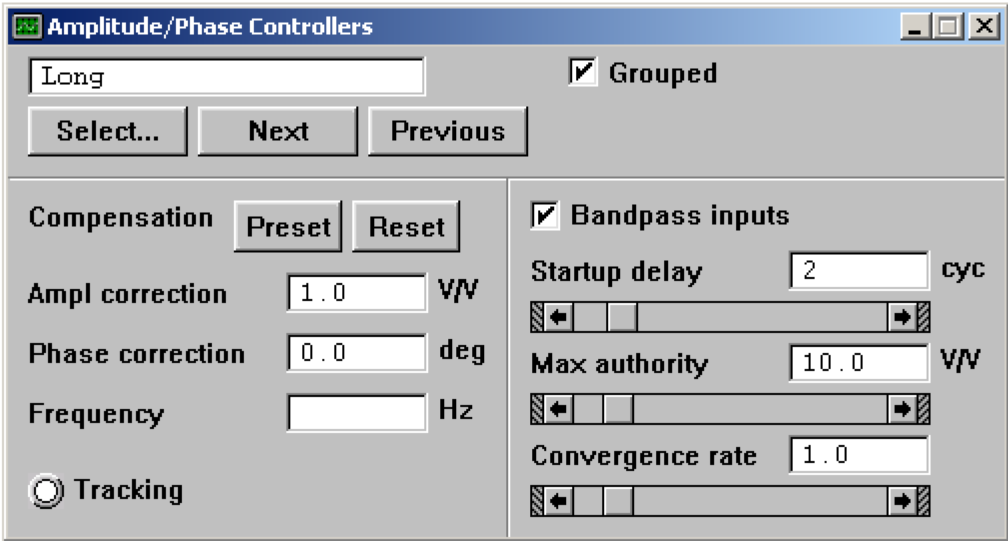
If instability occurs, immediately lower the convergence rate to 1.0 or less.</td></tr>
<tr><td>Coefficients text box</td><td>Displays textually the current values of the model coefficients. This information is also displayed graphically in the Impulse Response Function (IRF) Plotter. This display is updated using the Update button.</td></tr>
<tr><td>Update button</td><td>Update the Model Coefficients text display with current values of the model coefficients.</td></tr>
</table>

Adaptive Harmonic Cancellers (continued)

Control Descriptions

Control	Description
Canceller controls:	These controls are used when the adaptive harmonic canceller is running.
Reset button	Reset the canceller coefficients of all active harmonics to zero.
Tracking indicator	Displays the current state of the canceller coefficient adaptation process. The tracking indicator is green if coefficients are adapting, white if not. The conditions for tracking are: • The AHC mode is set to Tracking. • The canceller convergence rate is nonzero. The command waveform is not constant at zero or any other level.
Convergence rate slide bar and text box	Set the convergence rate of the canceller coefficient adaptation process. A value of zero means no adaptation; higher values increase the speed of the adaptation process at a cost of decreased cancellation quality. 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. **CAUTION** **Setting the convergence rate too high will cause system instability.** **Instability can result in uncontrolled actuator movement that can cause both equipment and specimen damage.** If instability occurs, immediately lower the convergence rate to 1.0 or less.
Harmonics selection boxes	Select the harmonics to be cancelled. Do not use the first harmonic unless you are cancelling cross-coupling disturbance on another channel (discussed in a later section).
Authority display box	Displays the maximum amplitude of any cancelling signal that AHC has added to the command. Not all of the signals will have this amplitude, only the largest one.
Max Authority text box	Set an upper limit on the amplitude of any cancelling signal that AHC adds to the command. This is a safety feature designed to limit the amplitude of motion should AHC's adaption process become unstable.

Amplitude/Phase Controllers



Panel Description

The Amplitude/Phase Controller panel allows you set up an amplitude/phase controller to correct feedback amplitude and phase errors when programming sine waveforms.

Access

Open the Amplitude/Phase Controller panel by selecting the **Controller** option from the **Operation** menu on the main panel, then dragging right to open the Controller submenu and selecting **Amplitude/Phase**. You can also open this panel by clicking on the **APC** icon on the Main panel.

When to Use the Panel

Use this panel only when the program (or command) signal is a sine wave. This controller minimizes the differences in amplitude and phase between the command and feedback.

NOTE *Adaptive phase control is turned on or off using the Adaptive Control button APC on the main panel.*

Amplitude/Phase Controllers (continued)

Background Information

Amplitude/Phase Control (APC) is a control compensation technique that augments a fixed-gain controller to correct for closed-loop amplitude and phase irregularities in order to improve control fidelity. It measures control system dynamics directly and modifies the control compensation accordingly in realtime, making it possible to adapt to changing system dynamics.

Control Descriptions

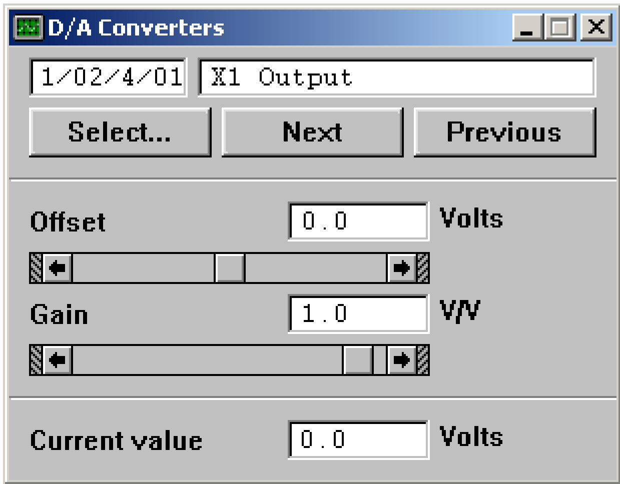
Control	Description
Channel list selector	Select an individual APC channel for manipulation or examination. The Select button calls up a dialog with all channels presented in a list from which a single channel can be selected. Next and Previous buttons cycle through the list without having to call up the channel selection dialog.
Grouped checkbox	Specify whether the selected channel is to be grouped with other channels for purposes of setting Bandpass Inputs, Startup Delay, Max Authority, and Convergence Rate. When checked, changes to any of these parameters will be broadcast to other channels in the group. When unchecked, changes to any of these parameters will not affect other channels
Compensation controls:	
Preset button	Presets the Ampl Correction to 0 and the Phase Correction to 1.
Reset button	Set both the amplitude correction and the phase correction to zero.
Ampl correction display text box	Displays the current amplitude correction being applied to the command. Also allows values to be entered so that APC can be set to correction values other than that provided by the Compensation Preset and Reset buttons.
Phase correction display text box	Displays the current phase correction being applied to the command. Also allows values to be entered so that APC can be set to correction values other than that provided by the Compensation Preset and Reset buttons.
Frequency display box	Displays the current frequency of the command.

Amplitude/Phase Controllers (continued)

Control Descriptions

Control	Description
Tracking indicator	Displays the current state of the coefficient adaptation process. The tracking indicator is green if coefficients are adapting, white if not. The conditions for tracking are: • The APC mode is set to Tracking. • The convergence rate is nonzero. • The command waveform is not constant at zero or any other level. • The number of sine cycles since the start of the command waveform is greater that the number of cycles of startup delay. .
Bandpass inputs checkbox	Specify that APC's input signals are to be bandpass filtered to remove harmonic noise. This is a desirable thing except in certain rarely encountered situations that require the maximum possible adaptation speed, making the slight slowdown due to the delay of the filters unacceptable. It is recommended that you leave this checked.
Startup delay slide bar and text box	Set the number of sine cycles after the start of the command that must elapse before adaptation can begin. This prevents adaptation during the transition from a stopped to a running state until transients have died out somewhat.
Max authority slide bar and text box	Set the maximum amplitude correction that APC is allowed to apply to the command. This is a safety feature designed to limit the amplitude of motion should APC's adaption process become unstable.
Convergence rate slide bar and text box	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 increased susceptibility to noise. The convergence rate should be no more than unity otherwise the potential for instability exists.

D/A Converters



Panel Description

The D/A Converters panel allows you to perform the following tasks:

- Select a specific user digital-to-analog (D/A) converter
- Adjust the offset and gain for the selected converter
- View the current voltage output value at the selected converter

Access

Open the D/A Converters panel by selecting the D/A Converters option from the **Calibration** menu on the main panel.

When to Use the Panel

Use the D/A Converters to periodically calibrate the D/A converters (or DACs) in the system to ensure that the input and output voltages are balanced.

Normally you do not need to calibrate D/A converters (or DACs). Any D/A converter calibration should be completed only by experienced MTS service personnel.

NOTE *Both offset and gain are saved in the Calibration file.*

D/A Converters (continued)

Control Descriptions

Control	Description
Conv text box	Shows the name of the currently selected channel. The adjacent channel ID box shows the number of the selected channel. Select a channel using the **Select...**, **Next**, or **Previous** buttons.
Select... button	Opens the converter selection panel, from which you can select a converter.
Next button	Selects the next converter in the selection panel list.
Previous button	Selects the preceding converter in the selection panel list.
Offset slide bar and text box	Adjusts the offset of the signal output by the converter. Use the **Offset** slide bar to set the D/A Converter for a current value of 0.00V. You can use the slide bar to set a value or you can enter it in the text box.
Gain slide bar and text box	Adjusts the gain of the signal output by the converter. Use the Gain adjustment to set the full-scale range of the D/A Converter. You can use the slide bar to set a value or you can enter it in the text box.
Current value text box	Shows the current value output by the selected converter. Not editable.

Data Player

Panel Description

The Data Player panel allows you to list the data channels and select a time history file for the program source.

Access

Open the Data Player panel by selecting the Data Player option from the **Operation** menu on the main panel. You can also open this panel by clicking on the **Program Source** icon on the Main panel when Data Player File is selected.

When to Use the Panel

Use the Data Player panel to list the data channels and choose a file to be played out as the program source when the Data Player selection is enabled for the program source on the Main panel.

First choose the desired channels and then select the file. It is very important that the number of channels and order of channels selected match the number and order in the selected file.

Tip: Always keep the natural order of channels as they are listed by the software in the Available list.

Playout File Information

When using a file for the playout source, the file must be in MTS binary format. The *Translate text to binary* option under the File menu on the Main panel will translate an ASCII text file to MTS binary format.

The text file to be translated must be in the following format:

> The first value in the text file must be the time period between samples, followed by the data in engineering units arranged in a single column.

The translator will prompt you for the ASCII text file. The converted file will be given the same name as the text filename but will have a *.bin* extension.

Playout File Information (con't)

Note that when a file is played out, the system does not automatically ramp up at the beginning of the file. It is assumed the file will contain this ramping data if it is required. The span will jump to 100% at the beginning of the file. The only exception to this is in the middle of the file, if the program is put into Stop mode, then the system will ramp down to 0% and ramp back up to 100% when it starts up again (Run mode enabled).

Data Player (continued)

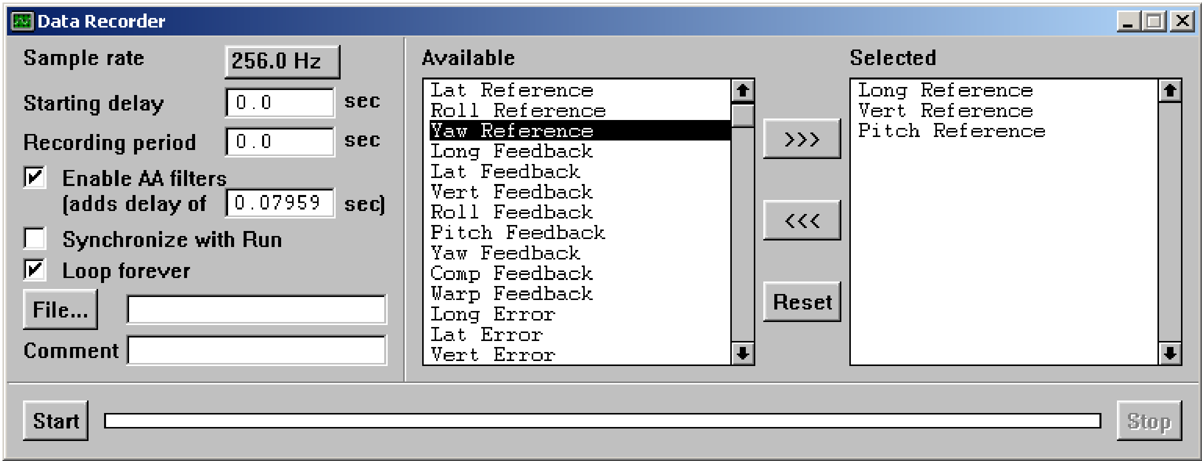
Playout File Information (con't)

You can scale the playout file by playing it out at a different sample rate than the recorded rate. The **Play Sample Period** input allows the user to input a playout sample period different from the recorded sample period.

Control Descriptions

Control	Description
File... button and text box	Selects the file which contains the playout data. The file must be in MTS binary format. The *Translate text to binary* option under the File menu on the Main panel can be used to convert an ascii text file to MTS Binary format.
File Sample Period text window	Displays the sample period of the recorded file.
Play Sample Period text box	Input the desired sample period for playing out the recorded file. This value will default to the File Sample Period.
File Length text window	Displays the playout file length.
Elapsed Time text window	Displays the amount of time that the file has been played out.
Pass _ of _ text boxes	Input the number if times to play the selected file. The current pass will be displayed.
Reset button	When pressed, resets the playout file to the beginning.
Channel Selection text boxes	Select the channels to be played out. The **Available** box shows the available channels. The **Selected** box shows the selected channels. To move a channel between boxes, first highlight the channel by placing the cursor on it and clicking once on the mouse button. Then click on the appropriate arrow to move the channel to the other box. Press the **Reset** button to clear the Selected box of all channels. Make sure the number of channels selected and the order of these selected channels matches the number and order in the selected playout file.
Reset button	When pressed, resets the playout file to the beginning.

Data Recorder



Panel Description

The Data Recorder panel allows you to:

- Record data from selected channels and store in a user selected file
- Set the sample rate, starting delay, and recording period
- Choose whether to start recording data when the START button is pushed, or to synchronize the data recording with the RUN button on the main panel

Access

Open the Data Recorder panel by selecting the Data Recorder option from the **Operation** menu on the main panel.

When to Use the Panel

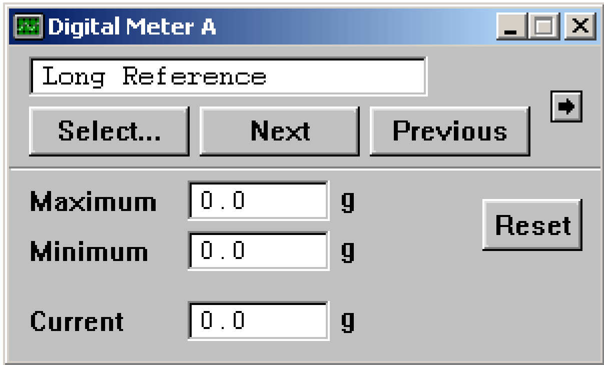
Use the Data Recorder panel to record data from selected channels and store the data in a file. The data in the file will be in MTS binary format. This data file can be converted to an ascii text format file by choosing the *Translate binary to text* option under the File menu option on the Main panel.

Data Recorder (continued)

Control Descriptions

Control	Description
Sample Rate pulldown menu	Select the recording sample rate. The available sample rates are 32, 64. 128, 256, 512, and 1024 Hz.
Starting delay text box	Input the time delay between when the Start (or Run) button is pressed and data recording begins.
Recording period text box	Input the period of time that the data recorder should run.
Enable AA Filters check box	When checked, a digital anti-aliasing filter is added to each selected signal. The software will select an appropriate filter type dependant on the sample rate. The frequency response of this AA filter can be viewed using the FRF panel. The AA filter will add a delay which is displayed for your reference. You may need to adjust the starting delay and/or extend the recording period, accordingly.
Synchronize with Run check box	If checked, data recorder will start when the Run button on the main panel is pressed (the Start button on the Data Recorder panel must also be on). If not checked, the data recorder will start as soon as the Start button is pressed.
Loop Forever check box	When checked, will record over and over again.
File… button	Input the filename where the recorded data is to be stored.
Comment text box	Use this text box to input a comment to be stored with the data. This comment box can be used to input information to identify the particular acquisition such as a Serial ID number, etc.
Signal Selection text boxes	Select the signals to be recorded. The **Available** box shows the available signals. The **Selected** box shows the selected signals. To move a signal between boxes, first highlight the signal by placing the cursor on it and clicking once on the mouse button. Then click on the appropriate arrow to move the signal to the other box.
Reset button	Pressing this button will clear the Selected box of all signals.
Start/Arm button	Starts data recording. If acquisition is synchronized, the Start button grays out after you click on it. Acquisition is then queued to start with the appropriate event.
Progress bar	After data acquisition starts, the progress bar grows from left to right, showing how much data has been recorded (0 to 100%).
Stop button	Stops data recording.

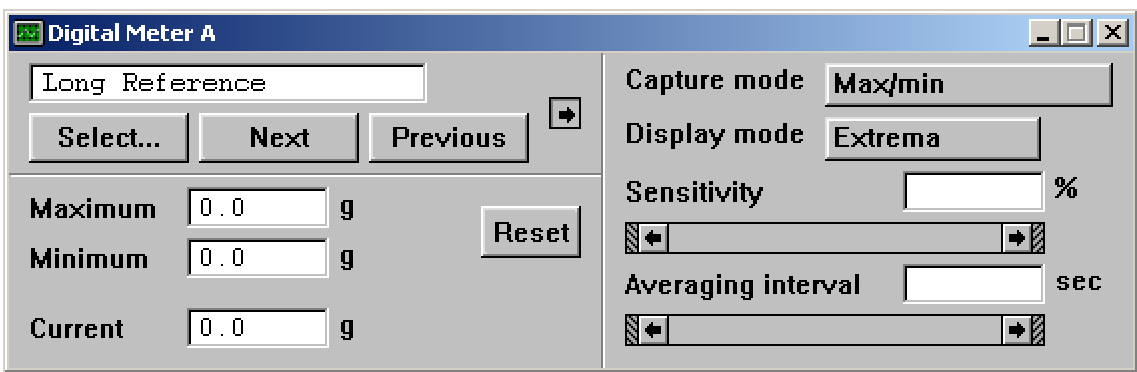
Digital Meter A or B



Panel Description The Digital Meter A or B panel allows you to monitor a signal.

Access Open the Digital Meter A or B panel by selecting the Digital Meter A or Digital Meter B option from the **Display** menu on the main panel.

Toggle the arrow to display the right side of the display panel as shown below:



When to Use This Panel Use either panel to read the present voltage value of the selected signal.

Digital Meter A or B (continued)

Background Information

The digital meters provide the following signal monitoring modes:

- **Max/min**

  Monitors the maximum and minimum signal values since the display session began or the reset button was last selected. Signal values are displayed in the Maximum and Minimum text boxes.

- **Peak/valley (banded)**

  Similar to Max/min mode, except the Reset button is automatically pressed after the signal reverses by an amount determined by the sensitivity adjustment. Thus changes in signal peaks and valleys can be continuously monitored. Can be used for cyclic and non-cyclic waveforms.

- **Peak/valley (timed)**

  Similar to Max/min mode, except the Reset button is automatically pressed after the signal reverses a quarter of a cycle as determined by the signal's current frequency. Thus changes in signal peaks and valleys can be continuously monitored. Can be used only for cyclic waveforms.

- **RMS/mean**

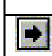
  Monitors the RMS and mean of a signal since the display session began or the reset button was last selected. The amount of signal averaging can be adjusted via the *Averaging Interval* slidebar/textbox. Can be used for cyclic and non-cyclic waveforms.

Control Descriptions

Control	Description
Signal text box	Shows the name of the current selected signal. Select a signal using the **Select...**, **Next**, or **Previous** buttons.
Select... button	Opens the signal selection panel, from which you can select a signal.
Next button	Selects the next signal in the selection panel list.
Previous button	Selects the preceding signal in the selection panel list.

Digital Meter A or B (continued)

Control Descriptions

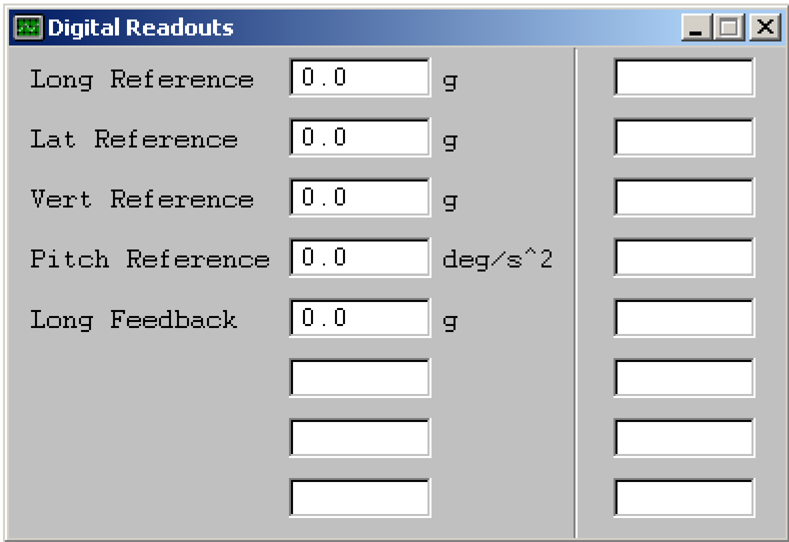
Control	Description
Maximum or **Peak** or **RMS** or **Amplitude** text box	Displays the **Maximum** value for the signal when Capture Mode is Max/Min and Display Mode is Extrema. Displays the **Peak** value for the signal when Capture Mode is Peak/valley and Display Mode is Extrema. Displays the **RMS** value for the signal when Capture Mode is RMS/Mean (Display Mode is grayed out). Displays the **Amplitude** of the signal when Capture Mode is Max/Min or Peak/valley and Display Mode is Amplitude/Base.
Minimum or **Valley** or **Mean** or **Base** text box	Displays the **Minimum** value for the signal when Capture Mode is Max/Min and Display mode is Extrema. Displays the **Valley** value for the signal when Capture Mode is Peak/valley and Display Mode is Extrema. Displays the **Mean** value for the signal when Capture Mode is RMS/Mean. (display Mode is grayed out) Displays the **Base** value of the signal when Capture Mode is Max/Min or Peak/valley and Display Mode is Amplitude/Base.
Current value text box	Displays the current value of the selected signal.
Reset button	Clears the **Minimum** and **Maximum** text boxes.
 arrow	Toggle the  arrow to open/close the right side of the display panel that contains the options described below.

Digital Meter A or B (continued)

Control Descriptions

Control	Description
Capture Mode pop-up menu	Selects a monitoring mode. The choices are: **Max/min** — display the maximum and minimum values of the signal in the Maximum and Minimum boxes. **Peak/valley (banded)** — display the peak and valley values of a signal determined by reversal outside a specified sensitivity band. **Peak/valley (timed)** – display the peak and valley values of a signal determined by reversal within an amount of time determined by the signal frequency. **RMS/Mean –** display the RMS and mean values of a signal averaged over a specified sliding time interval.
Display pop-up menu	Selects a display mode. The choices are: **Extrema** — Displays min/max or peak/valley values. See Capture mode above. **Amplitude/Base** — Alternative form of displaying extrema, where: $\text{Amplitude} = \frac{\text{max - min}}{2}$ and $\text{Base} = \frac{\text{max + min}}{2}$ NOTE: not available in RMS/mean capture mode
Sensitivity slide bar and text box	For peak/valley detection, sets the sensitivity of detection to a percentage of full-scale band. You can use the slide bar to set a value or you can enter it in the text box.
Averaging interval slide bar and text box	For RMS/Mean capture mode, sets the averaging interval. You can use the slide bar to set a value or you can enter it in the text box.

Digital Readouts



Panel Description

The Digital Readouts panel allows you to monitor a signal.

Access

Open the Digital Readouts panel by selecting the **Digital Readouts** option from the **Display** menu on the main panel.

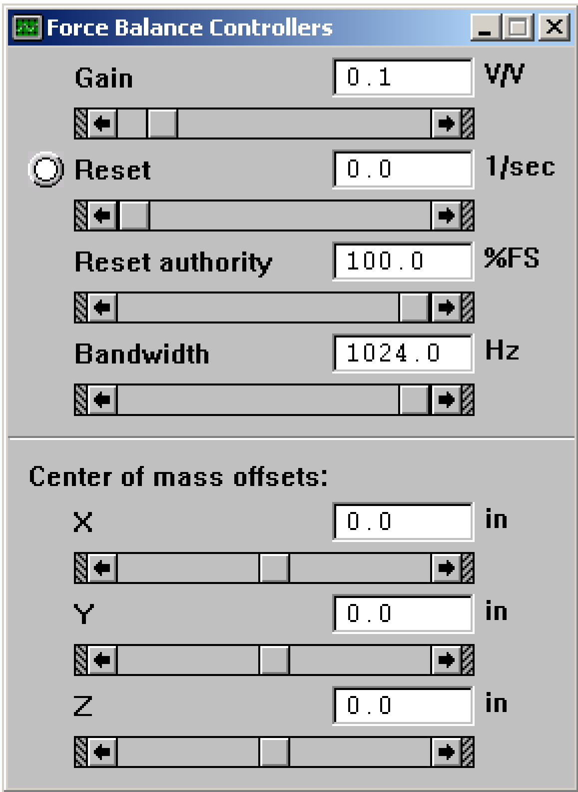
When to Use the Panel

Use this panel to read the present voltage value of a selected signal.

Control Descriptions

Control	Description
Numerical text box	Click near any display box to open a pulldown channel selection box. Select a channel. The selected channel and its value (in engineering units) are displayed.

Force Balance Controllers



Panel Description

The Force Balance Controllers panel allows you to setup and tune the force balance servo control loops. All current and reference gains are included in the parameters saved to a settings file.

Access

Open the Force Balance Controllers panel by selecting the **Controllers** option from the **Operation** menu on the main panel, then dragging right to open the Controllers submenu and selecting **Force Balance**.

When to Use the Panel

You can use the Force Balance Controllers panel to set up and adjust parameters for the Warp PID controllers.

Before making any adjustments, you may wish to use the **>>Copy>>** command to copy the current stable settings to the reference gains. If the system then becomes unstable, you can immediately click on the **<<Switch>>** button and restore the stable setting to current gains. You can then examine the gains that caused the instability.

Background Information

Each of the controls on the Force Balance Controllers panel affects the system in a distinct way. It is important to understand these effects before attempting to tune the system. Refer to Chapter 3, Understanding Control Principles, for more detailed information about the control system and servo control adjustments.

Force Balance Controllers (continued)

Control Descriptions

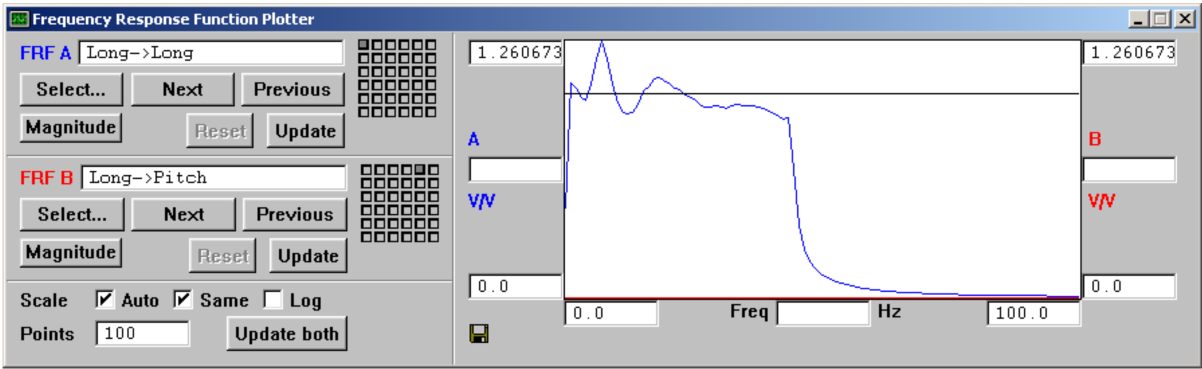
Control	Description
Channel text box **Select...** button **Next** button **Previous** button	Shows the name of the current selected channel. Select a channel using the **Select...**, **Next**, or **Previous** buttons. Opens the channel selection panel, from which you can select a channel. Selects the next channel in the selection panel list. Selects the preceding channel in the selection panel list.
Current gains and **Reference gains**	Gain parameters can be entered as **Current gains**, which go into effect immediately. **Current gains** can be copied to **Reference gains**, which are kept in memory but not used. The **<<Copy<<**, **<<Switch>>** and **>>Copy>>** buttons are used to move the complete set of gain parameters between Current and Reference. **>>Copy>>** Copies all current gain parameters to their corresponding reference gains. **<<Switch>>** Swaps all current gain parameters with their corresponding reference gains. **<<Copy<<** Copies all reference gain parameters to their corresponding current gains. The following gains are explained in more detail in Chapter 3. Chapter 6 explains how the gains are used in tuning the control loop.
Gain text box and slide bar	Adjusts the proportional gain for the selected channel. You can use the slide bar to set a value or enter it in the text box.

Force Balance Controllers (continued)

Control Descriptions

Control	Description
Gain text box and slide bar	Adjusts the proportional gain for the selected channel. You can use the slide bar to set a value or enter it in the text box.
Reset indicator	Indicates the state of the reset integrator. **White** – not integrating **Green** – integrating **Red** – has integrated up to maximum integral authority. You should review whether to increase the integral authority.
Reset text box and slide bar	Adjusts the reset (integral) gain for the selected channel. You can use the slide bar to set a value or enter it in the text box.
Reset Authority text box and slide bar	Adjusts the limit for the reset integrator. Input the value in % of full scale output. You can use the slide bar to set a value or enter it in the text box.
Bandwidth slide bar and text box	Adjusts the bandwidth of the low pass filter. You can use the slide bar to set a value or enter it in the text box.
Center of mass offsets	
X text box and slide bar	Inputs the X center of mass offset to minimize rotational motion.
Y text box and slide bar	Inputs the Y center of mass offset to minimize rotational motion.
Z text box and slide bar	Inputs the Z center of mass offset to minimize rotational motion.

FRP Plotter



Panel Description	The FRF (frequency response function) Plotter panel is used with adaptive inverse control and adaptive harmonic control. It allows you to display the frequency response characteristics of the selected channels. This panel is also used to display the forward FRF determined by the spectrum analyzer. The display plots magnitude or phase vs. frequency.
Access	Open the FRF Plotter panel by selecting the FRF Plotter option from the **Display** menu on the main panel.
When to Use the Panel	Use this panel to display the FRF for one or two channels. It allows you to identify cross coupling between channels. Before using this panel, use the Function Generator panel to set a random drive signal for the channel(s).
Background Information	The frequency response function, or FRF, is a mathematical model that accounts for the effects of a system on a signal.

It provides a linear approximation of the changes in phase and amplitude that occur in the frequencies making up a signal as that signal passes through a system. It is used within a component test to compensate for those changes.

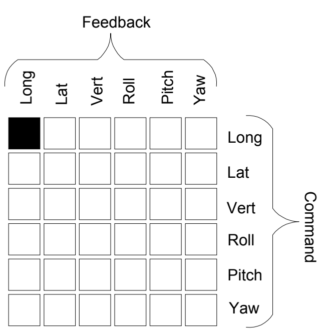
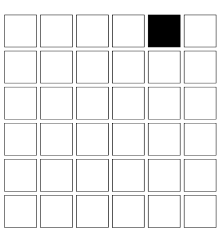
The system that the signal is played through contains the electronic and hydromechanical parts of the testing equipment, the transducers, and the test specimen. The response collected shows all the changes in phase and amplitude that the system produces in the signal. These changes are calculated and used to compensate for the effects of the system on the signal.

If any system component is significantly changed (for example, if a test specimen accelerometer is replaced) a new FRF should be measured for the system.

An FRF is measured by exciting the test system with a shaped random drive signal (whose frequency content is similar to the desired drive signal) and collecting responses to the excitation.

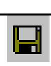
FRF Plotter (continued)

Control Descriptions

Control	Description
Channels select controls	
FRF A or **FRF B** text box	Shows the name of the selected channel. Select a channel using the **Select...**, **Next**, or **Previous** buttons.
Select... button	Opens the channel list box, from which you can select a channel. You can also select a channel by clicking in the appropriate box in the cross-coupling configuration diagram.
Next button	Selects the next channel in the list.
Previous button	Selects the preceding channel in the list.
Cross-coupling configuration diagram  	This diagram shows how each command signal is coupled to a feedback signal for adaptive control. The rows correspond to command signals, and the columns correspond to feedback signals. In the first example shown here, the first command (Long) is coupled to the first feedback (Long). The adaptive controller is said to be “on-diagonal,” coupling a command channel with its corresponding feedback channel. Each adaptive controller couples one command to one feedback, but these need not be associated with the same degree of freedom. In the second example shown here, the first command channel (Long) coupled to the third feedback channel (Pitch). In this configuration, the adaptive controller is said to be “off-diagonal,” coupling an actuator with a different transducer.

FRF Plotter (continued)

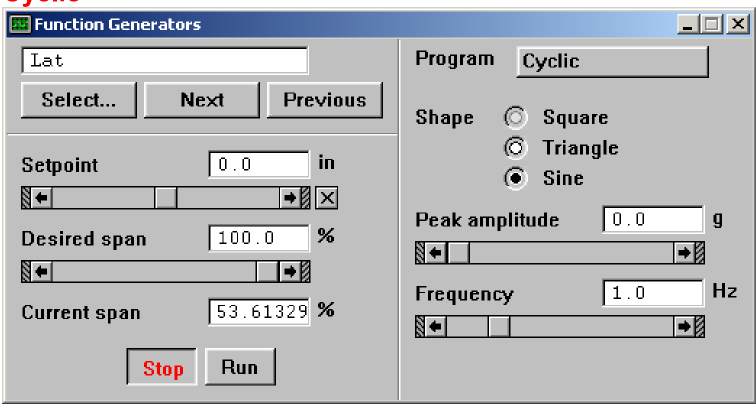
Control Descriptions

Control	Description
Magnitude/Phase pop-up menu	Selects the type of Y-axis data to be displayed. The choices are: Magnitude (in V/V) Phase (in degrees)
Reset button	The **Reset** button when activated is used with the spectrum analyzer. It resets the spectrum analyzer averaging to zero count and starts averaging again.
Update and Update both buttons	The **Update** button for each signal updates the display of adaptive control for that signal. The **Update both** button updates the display of adaptive control for both.
Scale checkboxes: **Auto**	Selects independent autoscaling. In this mode, the two signals are scaled to fill the entire display area, regardless of their relation to each other. Even if **Auto** scale is selected, you can change the frequency range of interest using the text boxes on the X axis.
Same	If this box is checked, the same scaling is applied to both signals
Log	If checked, plots on a logarithmic scale. Unchecked, plots on a linear scale.
Points text box	Selects and shows the number of points displayed at the selected scale. You can enter a number of points in this box (range 32 to 384).
Display area text boxes	The text boxes surrounding the display area show the values of the upper and lower ranges currently displayed. • The top and bottom text boxes on the right and left sides show the minimum and maximum values of the A and B traces (respectively); the right and left text boxes on the bottom of the monitor show frequency. • If you click on a specific point in the display area, a line appears, and the corresponding X and Y values will be shown in the text boxes in the right center, bottom center, and left center.
Save 	Click to save plotted values to a text file. A dialog box will appear to ask for a file name.

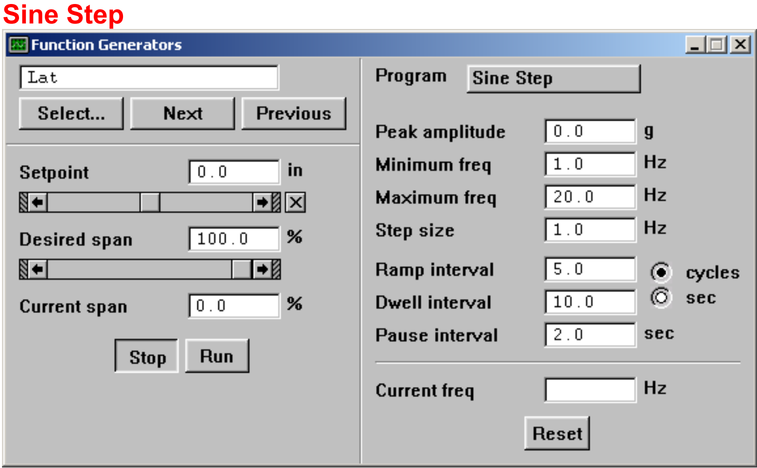
Function Generators

The following Function Generators are available:

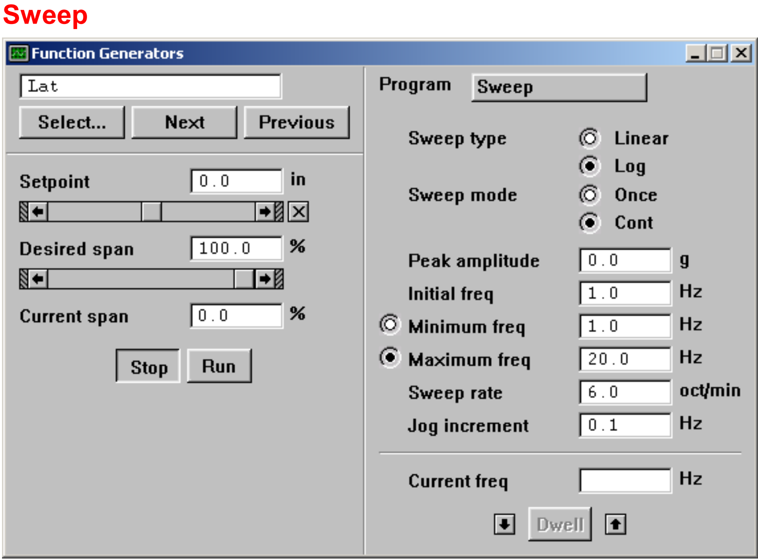
Cyclic



Sine Step

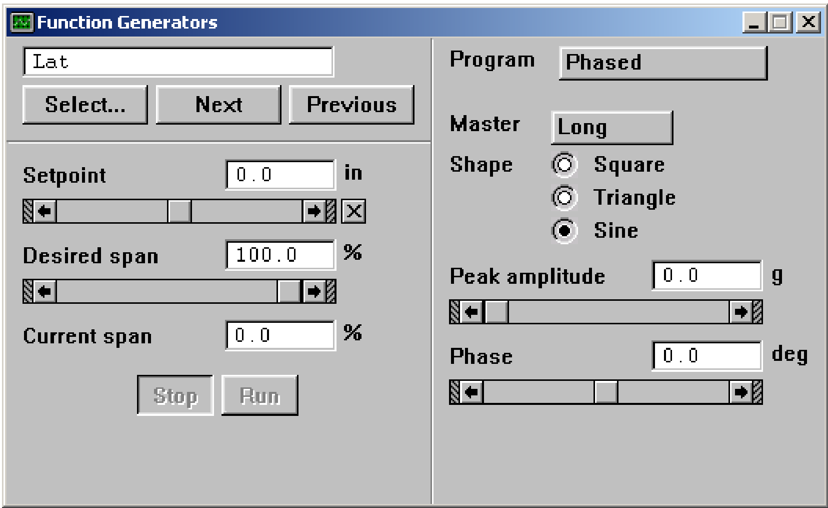


Sweep

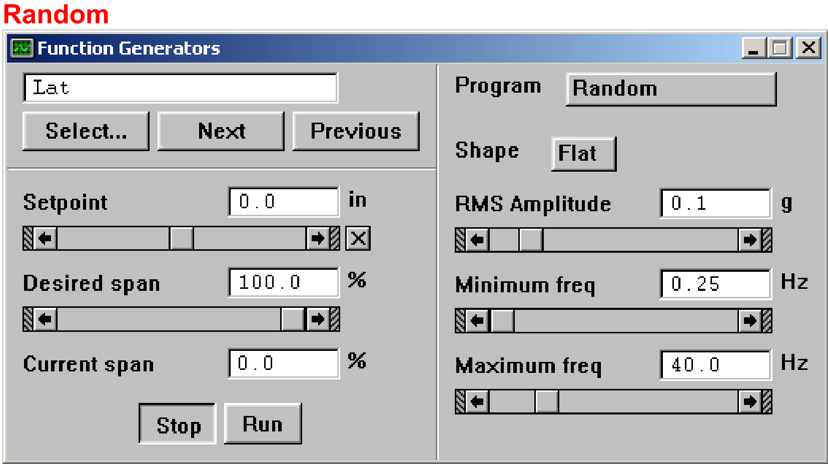


Function Generators (continued)

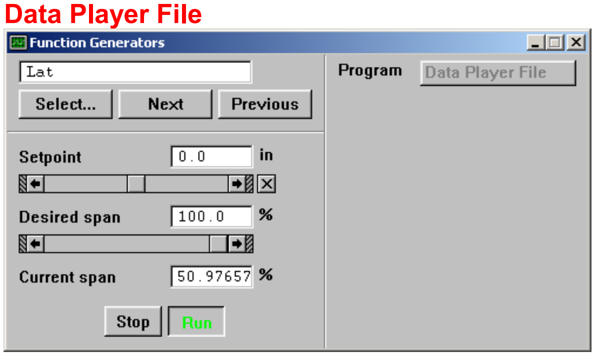
Phased



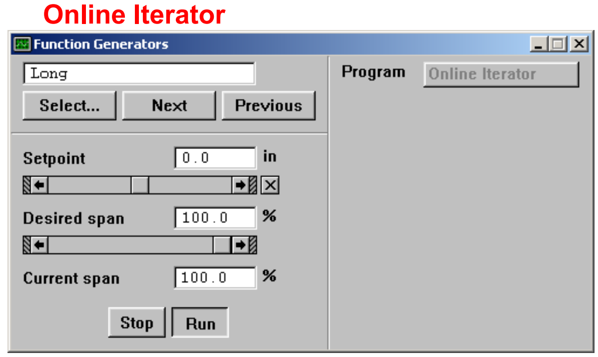
Random



Data Player File

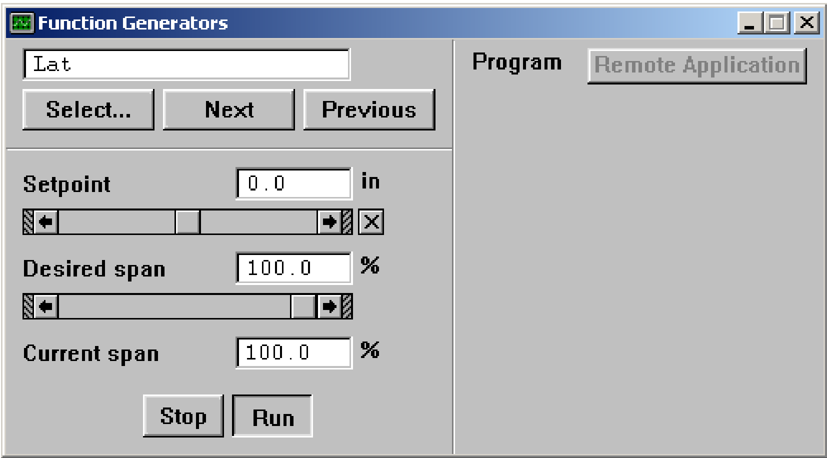


Online Iterator



Function Generators (continued)

Remote Application



Scramnet

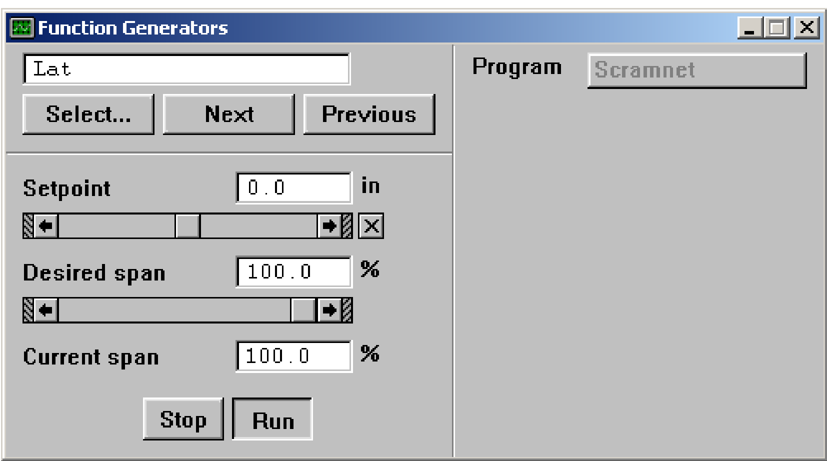
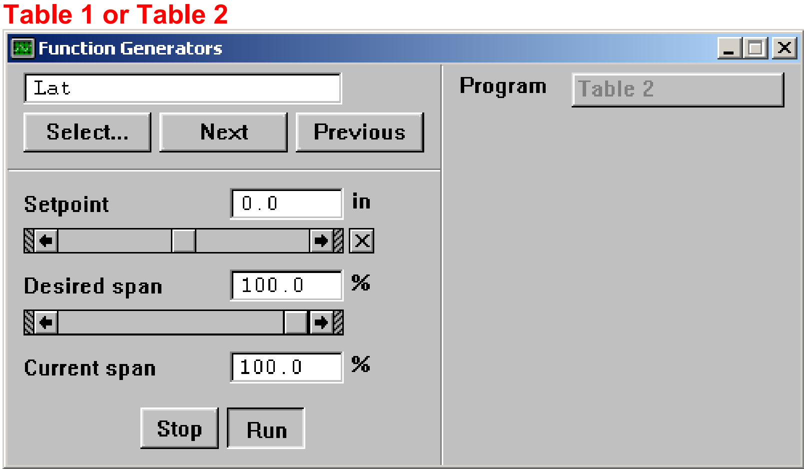


Table 1 or Table 2



Function Generators (continued)

Panel Description

The Function Generator panel allows you to select the program source and set the appropriate parameters.

Access

Open the Function Generator panel by selecting the Function Generator option from the **Operation** menu on the main panel. You can also open this panel by clicking on the **Program Source** icon on the Main panel when Function Generator is selected.

When to Use the Panel

You can use this panel to generate and apply a program the test system. Typically, you will want to use the function generator when you are tuning the servo control loops during test setup, but it can also be used for testing.

Important Information

WARNING

Whenever hydraulic pressure is applied, adjustment of the controls on the Function Generator panel can cause actuator movement.

Unexpected actuator movement can result in personal injury or equipment damage.

Ensure that all personnel are clear of the actuators, fixturing, and specimen before adjusting any Function Generator control. In addition, make sure that all operators know the effect of control adjustments before they make any adjustments.

Control Descriptions

Control	Description
Controls for all sources:	
Chan text box	Shows the name of the currently selected channel. The adjacent channel ID box shows the number of the selected channel. Select a channel using the **Select...**, **Next**, or **Previous** buttons.
Select... button	Opens the channel selection panel, from which you can select a channel.
Next button	Selects the next channel in the selection panel list.
Previous button	Selects the preceding channel in the selection panel list.

Function Generators (continued)

Control Descriptions

Control	Description
Controls for all sources (continued):	
Setpoint slide bar and text box	Sets the setpoint position for the channel. You can use the slide bar to set a value or you can enter it in the text box. • If hydraulic pressure is not applied, this setting identifies the position to which the actuator will ramp when hydraulic pressure is turned on. • If hydraulic pressure is applied, adjustment of this control ramps the actuator to the specified position.
Span slide bar and text box	Scales the amplitude of the command applied to the channel (regardless of selected source). You can use the slide bar to set a value or you can enter it in the text box. • If a program is currently running, it will be ramped to the new amplitude within 2 seconds. • If no program is currently running, the program will be ramped to the amplitude set by this control within 2 seconds when it is started. The **Span** value is multiplied by the **Desired Span** value (from the main panel, applied to all channels) to obtain the *channel span*. Refer to the main panel description for further information. Notice that if Span is set to a negative value, the signal will start in the opposite direction.
Current span text box	Not editable. Displays the current span of the function generated for the selected channel.

Function Generators (continued)

Control Descriptions (continued)

Control	Description
Controls for all sources (continued):	
Stop/Run buttons	Pressing the **Run** button starts the program on the selected channel. Ramps to the amplitude level set on the **Span** control within 2 seconds. Pressing the **Stop** button stops the program for the selected channel. Internally ramps the local span level to zero, but the value set on the Span control does not change. Notice that this does not start or stop a test program; use the Run/Hold on the main panel. Refer to the main panel description for information on starting or stopping a test program. If another channel is selected as the source, the Run/Hold button on this channel cannot be used. The master channel will control Run/Hold.
Program pop-up menu	Selects the programming source. The choices are: Cyclic — Data Player File* Sine Step — Table 1 or 2* Sweep — Remote Application* Phased — External (Scramnet)* Random — Online Iterator ****NOTE:*** If the main panel buttons are set for Data Player File, Remote Application, or Sramnet or Table 1/2 or Online Iterator are selected, all function generators are set to that same source. This menu is then grayed out and cannot be changed.

Function Generators (continued)

Control Descriptions (for Cyclic Program)

Control	Description
Controls for Cyclic source:	
Shape radio buttons (**Square**, **Triangle**, **Sine**)	Selects the shape of the function to be generated for the selected channel by the ***cyclic*** function generator.
Peak amplitude slide bar and text box	Sets the peak amplitude of the function to be generated for the selected channel by the ***cyclic*** function generator. You can use the slide bar to set a value or enter it in the text box. Ramps to new amplitude at the rate entered in the **Ramp Rates** panel.
Frequency slide bar and text box	Sets the frequency of the function to be generated for the selected channel by the *cyclic* function generator. You can use the slide bar to set a value or enter it in the text box. Ramps to new frequency at the rate entered in the **Ramp Rates** panel.

Control Descriptions (for Sine Step Program)

Control	Description
Controls for Sine Step Program:	
Peak amplitude text box	Sets the peak amplitude of the function to be generated by the ***step*** function generator. You can enter a value in the text box. Ramps to new amplitude at the rate entered in the **Ramp Rates** panel.
Minimum freq text box	Sets the frequency of the first step. You can enter a value in the text box.
Maximum freq text box	Sets the frequency of the last step. You can enter a value in the text box. Ramps to new frequency at the rate entered in the **Ramp Rates** panel.
Step size text box	Sets the step size for increasing from to minimum to maximum frequency.
Ramp interval text box	Sets the ramp time to reach peak amplitude for each step.
Dwell interval text box	Sets the time to stay at peak amplitude for each step.
Pause interval text box	Set the pause time between steps.
Current freq text	Displays the current frequency of the sweep function generator.
Reset button	Resets the step function to the minimum frequency.

Function Generators (continued)

Control Descriptions (for Sweep Program)

Control	Description
Controls for Sweep source:	
Sweep type pop-up menu	Selects the type of sweep (linear or logarithmic). The choices are: linear log
Sweep mode pop-up menu	Selects the sweep mode (one-time or continuous). The choices are: once cont If once is selected, the function generator sweeps to the end of its sweep range, then dwells.
Peak amplitude text box	Sets the peak amplitude of the function to be generated for the selected channel by the ***sweep*** function generator. You can enter a value in the text box.
Initial freq text box	Sets the initial frequency of the sweep function for the selected channel. You can enter a value in the text box.
Minimum freq radio button and text box	Sets the minimum frequency of the sweep function for the selected channel. You can enter a value in the text box. Click on this radio button if you wish to make the sweep first start moving from the initial frequency towards the minimum frequency.
Maximum freq radio button and text box	Sets the maximum frequency of the sweep function for the selected channel. You can enter a value in the text box. Click on this radio button if you wish to make the sweep first start moving from the initial frequency towards the maximum frequency.
Sweep rate text box	Selects the sweep rate of the function to be generated for the selected channel by the ***sweep*** function generator. You can enter a value in the text box. Units are defined as **dec/min** for the log sweep and **Hz/sec** for the linear sweep.
Jog increment	Sets the amount by which the dwell frequency can be raised or lowered by pressing the up or down jog arrows on the panel. For example if the jog increment is 0.1, pressing the down arrow lowers the dwell frequency by 0.1 Hz. You can enter a value in the text box.

Function Generators (continued)

Control Descriptions (for Sweep Program - continued)

Control	Description
Current freq text	Displays the current frequency of the sweep function generator. Not editable while sweeping but you can enter the desired frequency when in Dwell mode.
Dwell button	Stops the sweep and maintains the current frequency.
Jog arrow buttons	Jog the dwell frequency up or down. The Jog increment text box specifies how much the dwell frequency is raised or lowered. Use the up arrow button to raise the frequency by the Jog increment amount. Use the down arrow button to lower the frequency by the Jog increment amount.

Control Descriptions (for Phased program-source)

Control	Description
Controls for Phased channel source:	***NOTE:*** This can be considered a master/slave channel relationship. This source can only be selected if the master channel has a cyclic or sweep source. The master channel determines the frequency. The shape, amplitude and phase lag between the master/slave channels is selectable.
Master: pop-up menu	Selects the master actuator.
Shape radio buttons (**Square**, **Triangle**, **Sine**)	Selects the shape of the function to be generated for the slave channel.
Peak amplitude slide bar and text box	Sets the peak amplitude of the function to be generated for the slave channel. You can use the slide bar to set a value or enter it in the text box.
Phase slide bar and text box	Sets the phase lag between the master channel and the slave channel. You can use the slide bar to set a value or enter it in the text box.

Control Descriptions (for Random Program)

Control	Description
Controls for Random source:	Because TVC tuning is done almost exclusively in the frequency domain, the Random Function Generator is used to excite the system so that good transfer function estimates can be obtained. The Random Function Generator consists of a uniform distribution random number generator followed by a bandpass filter. This filter has four parameters adjustable from the Random Function Generator Panel:
Shape pop-up menu	Selects the shape of the function to be generated for the selected channel by the ***random*** function generator. 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. **1/F^2** – signal energy decreases with frequency as $1/f^2$ **1/F** - signal energy decreases with frequency as 1/f **Flat** - signal energy constant for all frequencies **F** - signal energy increases with frequency as f **F^2** - signal energy increases with frequency as f^2 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, "Flat" works well, but in displacement control, "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 1% of the maximum frequency when "1/F" and "1/F^2" shapes are selected.

Function Generators (continued)

Control Descriptions (for Random Program continued)

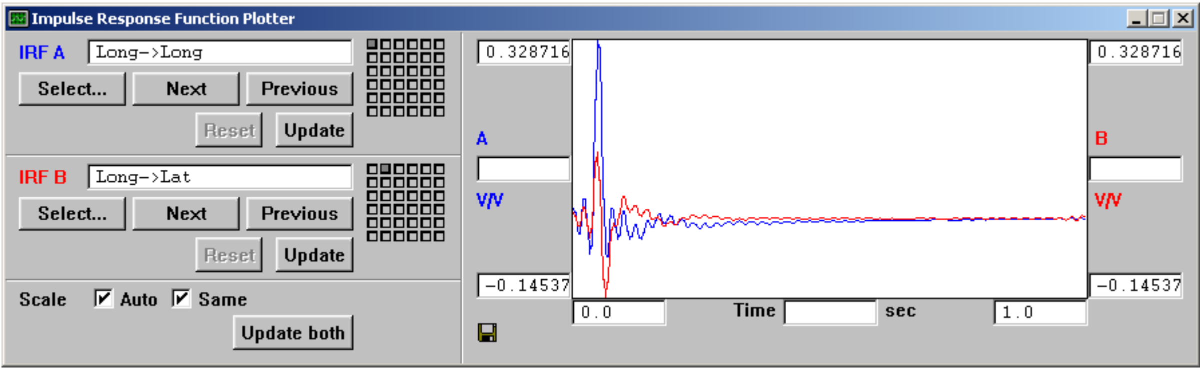
Control	Description
RMS Amplitude slide bar and text box	Selects the root mean square amplitude for the function to be generated for the selected channel by the ***random*** function generator. You can use the slide bar to set a value or enter it in the text box. Adjust the RMS amplitude to the minimum value possible to prevent damage to the test specimen. Keep in mind, however, that using too low of an amplitude will result in inaccurate estimates of the transfer function. 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 somewhat higher than RMS amplitude.
Minimum freq slide bar and text box	Selects the minimum frequency content for the signal to be generated for the selected channel by the ***random*** function generator. You can use the slide bar to set a value or enter it in the text box. 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 velocity and acceleration control modes, this frequency should match the cut-in frequency of the Reference Generator. NOTE: For $1/f^2$ or $1/f$, minimum frequency cannot be zero. If zero, it will automatically be set to same scale non-zero frequency value.
Maximum freq slide bar and text box	Selects the maximum frequency content for the signal to be generated for the selected channel by the ***random*** function generator. You can use the slide bar to set a value or enter it in the text box. This is the cutoff frequency of the bandpass filter. Set this according to the highest frequency to which you expect to control.

Function Generator (continued)

Control Descriptions (for Others)

Control	Description
	NOTE: The following control are not selectable via the Function Generator panel. They are for display purposes only and are selected via the Main panel.
Data Player File	This option indicates that the program command to the selected actuator comes from playing a data file. Refer to **Data Player** panel information.
Online Iterator	This option indicates that the program command to the selected actuator comes from the Online Iterator panel. Refer to **Online Iterator** panel information.
Remote Application	This option indicates that the program command to the selected actuator is generated by a remote source to be determined by the user (i.e. STEX).
Scramnet	This option indicates that the program command is generated from Scramnet.
Table 1 or Table 2	This option indicates that the program command to the selected actuator comes from the other controller.

IRF Plotter



Panel Description

The IRF (impulse response function) Plotter panel is used for initial setup of adaptive inverse control and adaptive harmonic control. It allows you to select one or two channels, then view the impulse response characteristics of the adaptive filters for the selected channel(s).

Access

Open the IRF Plotter panel by selecting the IRF Plotter option from the **Display** menu on the main panel.

When to Use the Panel

Consult MTS before using this panel. Normally, you will not have to use it. (See NOTE below.)

Background Information

The system impulse response interval is a function of your system—the time it takes the system response to settle after a step command. You normally set the adaptive filter to a value slightly longer than this interval, to make sure the adaptive control is not applied before it can take effect. Too short an interval results in wandering coefficients. Too long an interval results in slower convergence.

The IRF (impulse response function) is plotted as gain vs. time.

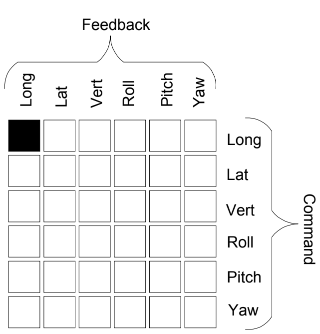
NOTE MTS has provided you with a default impulse response suited to your system. If you are using both stroke and acceleration adaptive control, MTS has provided a default for each type of control. If these settings seem wrong, or if you have any other questions about setting adaptive control parameters, consult MTS.

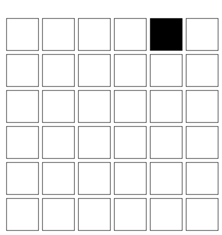
IRF Plotter (continued)

Control Descriptions

<table>
<tr><th>Control</th><th>Description</th></tr>
<tr><td>Channels select controls</td><td></td></tr>
<tr><td>IRF A or IRF B text box</td><td>Shows the name of the selected channel.

Select a channel using the Select..., Next, or Previous buttons.</td></tr>
<tr><td>Select... button</td><td>Opens the channel list box, from which you can select a channel. You can also select a channel by clicking in the appropriate box in the cross-coupling configuration diagram.</td></tr>
<tr><td>Next button</td><td>Selects the next channel in the list.</td></tr>
<tr><td>Previous button</td><td>Selects the preceding channel in the list.</td></tr>
<tr><td>Reset button</td><td>The Reset button when activated is used with the spectrum analyzer. It resets the spectrum analyzer averaging to zero count and starts averaging again.</td></tr>
<tr><td>Update and Update both buttons</td><td>The Update button for each signal updates the display of adaptive control for that signal. The Update both button updates the display of adaptive control for both.</td></tr>
<tr><td>Cross-coupling configuration diagram



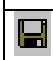

</td><td>This diagram shows how each command signal is coupled to a feedback signal for adaptive control. The rows correspond to command signals, and the columns correspond to feedback signals.

In the first example shown here, the first command (Long) is coupled to the first feedback (Long). The adaptive controller is said to be “on-diagonal,” coupling a command channel with its corresponding feedback channel.

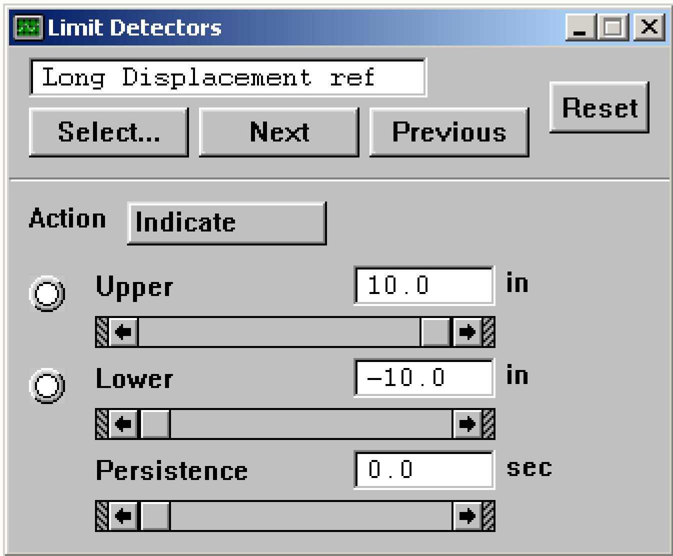
Each adaptive controller couples one command to one feedback, but these need not be associated with the same degree of freedom. In the second example shown here, the first command channel (Long) coupled to the third feedback channel (Pitch). In this configuration, the adaptive controller is said to be “off-diagonal,” coupling an actuator with a different transducer.</td></tr>
</table>

IRF Plotter (continued)

Control Descriptions (continued)

Control	Description
Scale checkboxes:	
Auto	Selects independent autoscaling. In this mode, the two signals are scaled to fill the entire display area, regardless of their relation to each other.
Same	If this box is checked, the same scaling is applied to both signals
Display area text boxes	The text boxes surrounding the display area show the values of the upper and lower ranges currently displayed. • The top and bottom text boxes on the right and left sides show the minimum and maximum values of the A and B traces (respectively); the right and left text boxes on the bottom of the monitor show frequency. • If you click on a specific point in the display area, a dot appears, and the corresponding X and Y values will be shown in the text boxes in the right center, bottom center, and left center.
	When pressed, saves plotted values into a text file. Saved data will appear in 2 or 3 columns. • Column 1 – Time axis data • Column 2 – IRF A data • Column 3 – IRF B data

Limit Detectors



Panel Description

The Limit Detector panel allows you to:

- Select a specific software signal for which a limit can be set
- Choose the action to be taken if a limit is exceeded
- Set an allowable operating range and persistence value for the signal
- Identify if an upper or lower out-of-limit has occurred
- Reset the software limit detector circuit

Access

Open the Limit Detector panel by selecting the Limit Detectors option from the **Operation** menu on the main panel. You can also open this panel by clicking on the **Limits** icon on the Main panel.

When to Use the Panel

Use the panel to set safety limits for the test system during test specification. This panel can be used to set software limits for the following signals:

displacement reference
velocity reference
acceleration reference
displacement feedback
velocity feedback
acceleration feedback
tracking error
valve drive

Limit Detectors (continued)

Important Information

The limit detectors are designed to protect equipment from damage. They are not designed, and should not be used, to protect personnel from injury.

The limit detectors are enabled and disabled from the main panel. If not enabled, they will not set an indicator or interlock.

Background Information

A limit event for a particular signal indicates that the signal has exceeded its upper or lower limit. The upper and lower limits establish a range of values that represent a desired system operating range. This band also represents the range where valid test data can be ensured. The persistence value is a time (in seconds) that an upper or lower out-of-limit condition can persist without causing an interlock.

When an out-of-limit condition occurs, the Message Log panel identifies the specific out-of-limit condition.

Control Descriptions

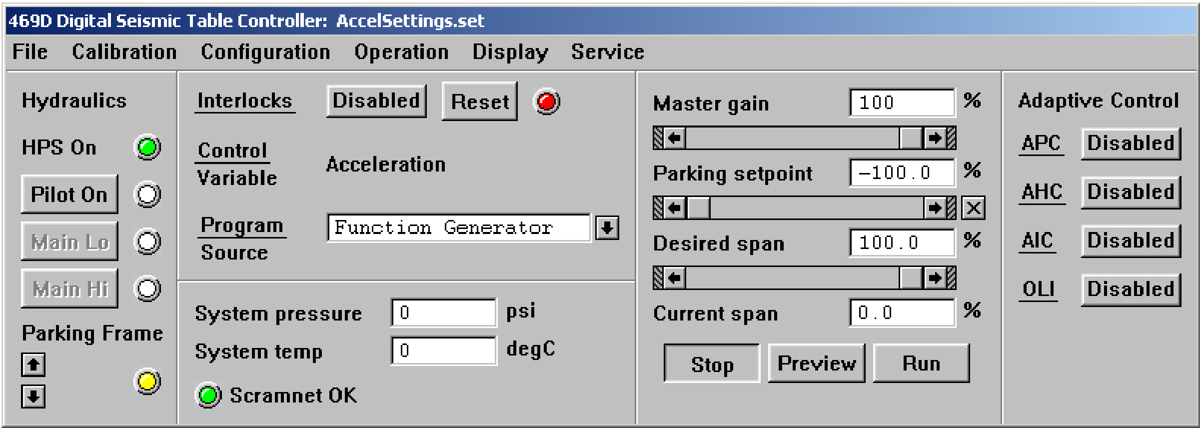
Control	Description
Det text box	Shows the name of the current selected signal. Select a signal using the **Select...**, **Next**, or **Previous** buttons.
Select... button	Opens the signal selection panel, from which you can select a signal.
Next button	Selects the next signal in the selection panel list.
Previous button	Selects the preceding signal in the selection panel list.
Reset button	When pressed, clears the **Upper** and **Lower** indicators and any software interlocks generated by the out-of-limit condition, if the channel is within limits.

Limit Detectors (continued)

Control Descriptions (continued)

Control	Description
Action pop-up menu	Select the result of an out-of-limit condition. Selections are: • **Indicate** – This selection causes the indicator to light only while the signal is outside of the limit. When the signal returns inside the limit, the indicator goes out. • **Alert** – This selection causes the indicator to light and latch. When the signal returns inside the limit, the indicator remains lit until the **Reset** button is used. The out-of-limit condition will be recorded in the message log. • **Program Abort**– This selection causes the system to trigger a program abort if the signal goes outside the limit where the master span will be ramped to zero at a rate entered in the **Ramp Rates** panel. The **Reset** button is required to reset the system. The out-of-limit condition will be recorded in the message log. • **Interlock** – This selection causes the system to trigger an Emergency Stop if the signal goes outside the limit. The **Reset** button is required to reset the system. The out-of-limit condition will be recorded in the message log.
Upper slide bar and text box	Sets the upper limit of the selected signal. Note that when you set the upper limit value, the lower limit is automatically set to the negative of the upper limit value. If you desire a different lower limit value, you should change it using the lower slide bar after setting the upper limit.
Upper indicator	Lights when an out-of-limit condition occurs for the upper limit.
Lower slide bar and text box	Sets the lower limit of the selected signal. Setting this value does not affect the upper limit value.
Lower indicator	Lights when an out-of-limit condition occurs for the lower limit.
Persistence slide bar and text box	Sets the time, in seconds, that an upper or lower out-of-limit condition can persist without causing an interlock.

Main Panel



Panel Description

The main panel allows access to all other parts of the Digital Seismic Table Controller application. It includes both menus and system controls. The following menus are provided:

- **File**—allows you to add comments to the message log, change passwords for access privileges, close windows, restore or save settings, convert files from binary to text format or visa versa, and quit the application
- **Calibration**—allows you to calibrate A/D and D/A converters, AC conditioners, DC conditioners, and valve drivers, and save or restore the calibration values.
- **Configuration**—allows you to configure units, observers, and ramp rates
- **Operation**—allows you to setup TVC controller, adaptive controller, online iteration, function generator, data recorders, limit detectors, and spectrum analyzers
- **Display**—allows you to use digital meters and readouts, read the message log, use FRF and IRF plotters and the digital oscilloscope

Note that you can click on an underlined icon on the main panel to open the associated panel for that item.

Main Panel (continued)

System controls on the main panel allow you to perform the following tasks:

- Monitor the current settings file
- Enable and monitor hydraulics
- Raise, lower and monitor parking frame
- Enable or disable limits
- Reset limit/interlock conditions
- Monitor the control mode
- Monitor the program source
- Set the master gain and setpoint
- Set the desired span and monitor current span
- Stop, run or preview a program
- Enable/disable Adaptive Control
- Enable/disable Online Iteration

Access

The main panel opens when you start the application. It cannot be closed except by quitting the application.

When to Use the Panel

Use this panel to set system controls and to access all other panels.

Control Descriptions

Control	Description
Hydraulics	
HPS On status indicator	The status indicator will turn green when the pumps reach the system operating pressure.
Pilot On button and status indicator	Turns on/off the pilot pump. The status indicator will turn green when pilot pressure to the servovalves is achieved.
Main Lo button and status indicator	Applies low pressure to the actuators. The status indicator will flash yellow until low pressure is achieved. Then the indicator shows a steady yellow for low pressure.
Main Hi button and status indicator	Applies high pressure to the actuators. The status indicator will turn green when the system is in high-pressure mode.
Parking Frame arrows and status indicator	Click on the arrow to raise the parking frame to home position. Click on the arrow to lower the parking frame to home position. Status indicator indicates the following: **Green** – parking frame is down (safe to run the system) **Yellow** – parking frame is in between **Red** – parking frame is up (NOT safe to run the system)

Main Panel (continued)

Control Descriptions (continued)

Control	Description
Interlocks pop-up menu	Enables/disables the software and hardware limit detectors. The hardware limit detectors are only enabled **if** the "hardware limits" disable control is not checked on the AC/DC Conditioner panels.
Interlocks Reset button	Use the **Interlocks Reset** button to clear the hardware and software limit status indicators located on the Conditioners and Limit Detector panels and the system E-STOP chain.
Control Variable display	Displays the selected control mode (displacement, velocity, or acceleration). The control mode is selected on the Three-Variable Controller panel.
Program display	Select the desired function generator program source. **Function Generator** - setup function using Function Generator panel **Data Player File** - select file using Data Player panel **External (Scramnet) -** input external digital signal from scramnet **Remote Application -** the program command to the selected actuator is generated by a remote source to be determined by the user (i.e. STEX). **Table 2** - program command to the selected actuator comes from the Table 2 controller.
System pressure display box	Displays the system oil pressure.
System temp display box	Displays the system oil temp.
Scramnet OK indicator	Indicates that Scramnet is connected and functioning properly.
Master Gain slide bar and text box	Adjusts the master gain. You can use the slide bar to set a value or enter it in the text box.
Parking Setpoint slide bar and text box	Adjusts the park and unpark setpoint position. You can use the slide bar to set a value or enter it in the text box.
Desired span slide bar and text box	Adjusts the desired span of the command signal. You can use the slide bar to set a value or enter it in the text box.
Current span display	Shows the current value of the span. The master span may take time to ramp up to its set value. This shows the actual value, at any moment.

Main Panel (continued)

Control Descriptions (continued)

Control	Description
Stop/Run/Preview buttons	Controls the program. **Stop** - stops the test program. Span will ramp to zero. System returns to setpoint levels **Preview**— allows user to evaluate (preview) command time history while hydraulic power is on. The program runs without commands being sent to the servo controller. Active only in velocity or acceleration control modes. Use Preview to verify that the program will not exceed the mechanical limits. **Run** - enables and runs the program.
Adaptive Control buttons	
APC pulldown menu	Enables or disables amplitude/phase control. **Disabled**: APC is off. **Frozen**: APC is on and controlling, but coefficients are unchanging. This mode is not recommended for normal operation. If you freeze the coefficients and then change the command frequency, the amplitude correction corresponding to the frozen coefficients may be inappropriately large at the new frequency, resulting in damage to your specimen and test system. **Tracking**: APC is on and controlling, and coefficients are changing. This is the mode recommended for normal operation.

Main Panel (continued)

Control Descriptions (continued)

<table>
<tr><th>Control</th><th>Description</th></tr>
<tr><td>AHC pulldown menu</td><td>Enables or disables adaptive harmonic canceller.
Disabled: AHC is off.

Frozen: AHC is on and cancelling, but canceller coefficients are unchanging. This mode is not recommended for normal operation. If you freeze the coefficients and then change the command frequency, the harmonic amplitude corresponding to the frozen coefficients may be inappropriately large at the new frequency, resulting in damage to or destruction of your specimen and test system.

Tracking: AHC is on and cancelling, and canceller coefficients are changing. This is the mode recommended for normal operation.

Training: AHC is on but not cancelling. Plant input and output are passively monitored while model coefficients are updated. This mode is used to determine model coefficient values prior to running Frozen or Tracking modes.</td></tr>
<tr><td>AIC pulldown menu</td><td>Enables or disables adaptive inverse control.

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.</td></tr>
</table>

Main Panel (continued)

Control Descriptions (continued)

<table>
<tr><th>Control</th><th>Description</th></tr>
<tr><td>OLI pulldown menu</td><td>Enables or disables online iteration.

Disabled: OLI is off.

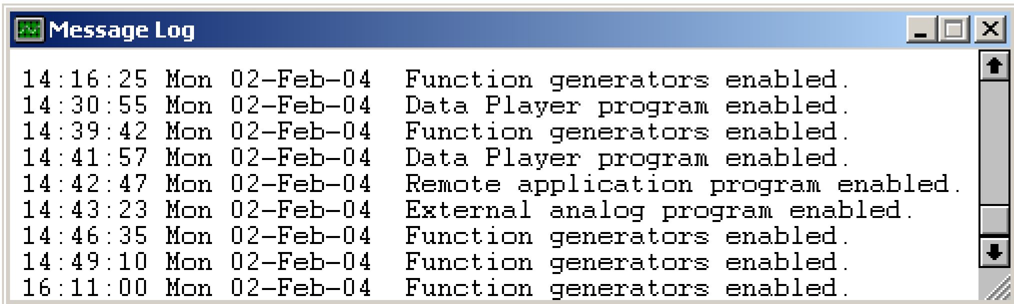
Frozen: OLI is on, but advancing to the next drive file at the end of the current iteration is inhibited. Use this mode if you want to OLI to monitor error statistics when playing out a final drive file.

Tracking: OLI is on, and advancing to the next drive file at the end of the current iteration is enabled. Use this mode to develop a final drive file.

When you turn on OLI to Frozen or Tracking, AIC is automatically turned on in Frozen mode for you. When you turn off OLI, AIC is automatically turned off.

You can change AIC to Tracking mode if you want AIC's inverse transfer function to update during iteration. In certain strongly nonlinear systems where the inverse transfer function varies significantly with signal level, this feature may help the iteration process to converge. However, because most systems converge nicely without this feature, and because the potential for AIC divergence in Tracking mode, we recommend that you leave AIC in Frozen mode.</td></tr>
</table>

Message Log



Panel Description

The Message Log panel allows you to read messages generated by system events. Messages are saved to a file called **message.log**. This file records many system actions automatically.

Access

Open the Message Log panel by selecting the Message Log option from the **Display** menu on the main panel.

In this view, the message log can be read but not changed. To add data to the message log, use the Add comment... option on the **File** menu.

When to Use the Panel

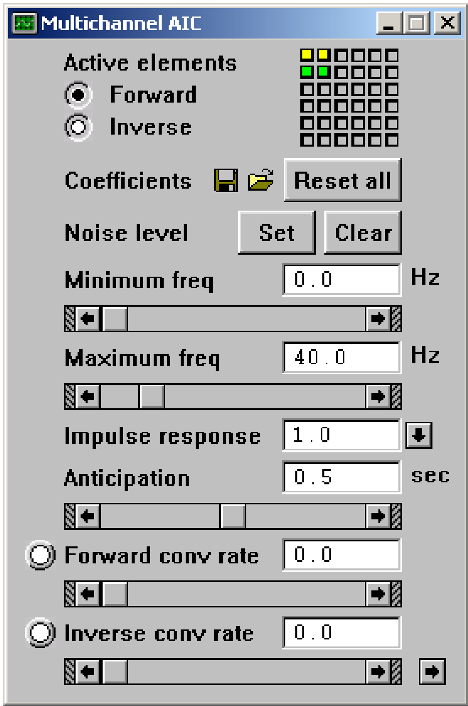
Use this panel to read the message log. Only messages from the current session are displayed. The file **message.log**, however, keeps a running list of all messages from all sessions.

NOTE *This file must periodically be deleted to prevent it from growing large and affecting performance. (Although it would take a very long time.)*

Control Descriptions

Control	Description
Scroll bar	Use the scroll bar to scroll through messages in the message log.

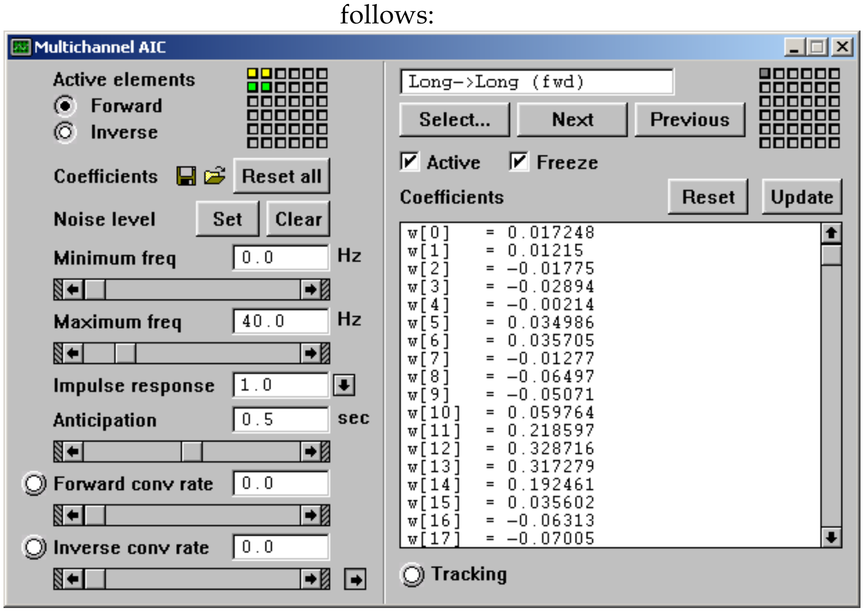
Multichannel AIC



Panel Description The Adaptive Inverse Controller panel allows you to set up an adaptive inverse controller.

Access Open the Adaptive Inverse Controller panel by selecting the **Controller** option from the **Operation** menu on the main panel, then dragging right to open the Controller submenu and selecting **Adaptive Inverse**. You can also open this panel by clicking on the **AIC** icon on the Main panel.

Toggle the arrow to display the right side of the display panel as follows:



Multichannel AIC (continued)

When to Use the Panel

Although adjustments are described later in this section, in normal use you will need to make few adjustments.

NOTE *Adaptive inverse control is turned on or off using the Adaptive Control button AIC on the main panel.*

Background Information

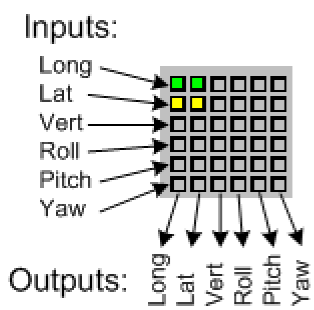
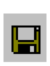
Adaptive Inverse Control (AIC) is a control compensation technique that augments a fixed-gain controller to correct for closed-loop gain and phase irregularities in order to improve control fidelity. In addition, in multichannel control systems with cross-coupled dynamics, it greatly reduces cross-coupling 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.

Control Descriptions

Control	Description
Coefficients Forward/Inverse radio button selector	Specify which transfer function matrix, forward or inverse, is the focus of various controls and displays, namely: • Activation Status grid display • Matrix Element list selector • Matrix Element grid selector • Frequency Response Function (FRF) Plotter grid selectors • Impulse Response Function (IRF) Plotter grid selectors

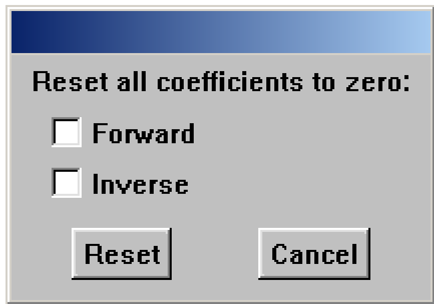
Multichannel AIC (continued)

Control Descriptions

Control	Description
Activation Status grid display	Displays the activation status of a transfer function matrix element by color: The element is active and its coefficients are adapting. The element is active but its coefficients are frozen (not adapting). 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. The Forward/Inverse radio button selector determines which transfer function matrix status is displayed.
	Saves the current values of filter coefficients to a text file. Used to temporarily save coefficients obtained during the training process. NOTE: This is only a temporary file; the final settings should be saved in the *settings.set* file by clicking **Save Settings** under the file menu.
	Opens and restores the temporary file saved above. This is useful for backing up intermediate training results in case something goes wrong.

Multichannel AIC (continued)

Control Descriptions

<table>
<tr><th>Control</th><th>Description</th></tr>
<tr><td>Reset all button</td><td>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.
</td></tr>
<tr><td>Noise Level Set and Clear buttons</td><td>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.

WARNING

Setting the noise level while adaptive control is tracking will cause unexpected actuator movement.

Unexpected actuator movement can result in personal injury or equipment damage.

Before setting the noise level, make sure adaptive control is frozen. Click on the Frozen button.

NOTE: Setting the noise threshold while system is in motion will cause tracking to cease altogether. In this case, stop the system, click the “Clear noise level” button, and then the “Set noise level” button.</td></tr>
<tr><td>Minimum and Maximum freq text boxes

Impulse response text box</td><td>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.

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.</td></tr>
</table>

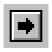
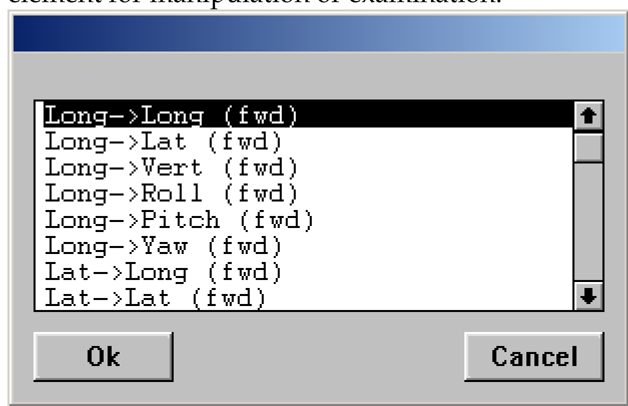
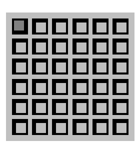
Multichannel AIC (continued)

Control Descriptions (continued)

Control	Description
Anticipation slide bar and text box	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 and **Inverse Convergence Rate** slide bars and text boxes	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. **CAUTION** **Setting the convergence rate too high will cause system instability.** **Instability can result in uncontrolled actuator movement that can cause both equipment and specimen damage.** If instability occurs, immediately lower the convergence rate to 1.0 or less.
Forward and **Inverse Convergence Rate** 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.

Multichannel AIC (continued)

Control Descriptions (continued)

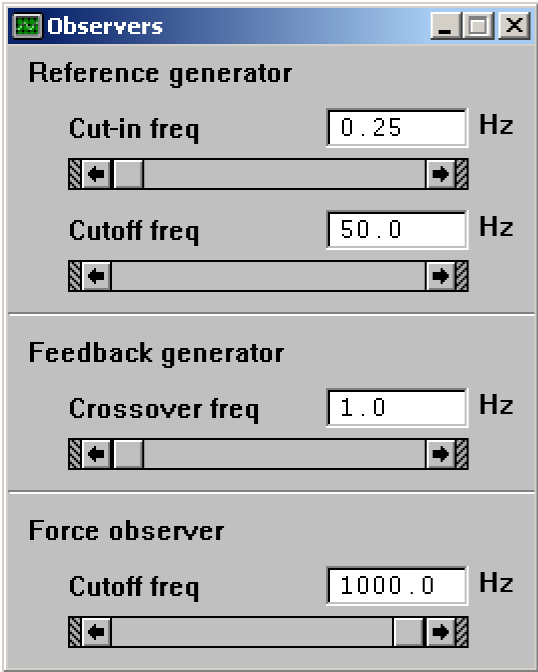
Control	Description
 arrow	Expand the panel so that the right half pane is visible.
Matrix Element list selector	Select an individual transfer function matrix element for manipulation or examination.  The Select button calls up a dialog with all elements presented in a linear list from which a single element can be selected. Next and Previous buttons cycle through the list without having to call up the element selection dialog. The Forward/Inverse radio button selector determines which transfer function matrix elements are in the list.
Matrix Element grid selector 	Select individual transfer function matrix elements for manipulation or examination by clicking on box corresponding to the desired element. The Forward/Inverse radio button selector determines which transfer function matrix elements are available. Note that Matrix Element grid selector looks superficially similar to the Activation Status grid display. 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.

Multichannel AIC (continued)

Control Descriptions (continued)

Control	Description
Active checkbox	Activate or deactivate a particular element within a transfer function matrix. See the section "Pruning the Transfer Function Matrix" below.
Freeze checkbox	Freeze or unfreeze coefficient adaptation of a particular transfer function matrix element. Its use is described in detail in the sections on transfer function training below.
Coefficients Reset button	Reset the coefficients of a particular transfer function matrix element to zero.
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.
Element Tracking indicator	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.

Observers



Panel Description

The Observers panel allows you to configure the Reference generator and Feedback generator for optimum use. The Observers Panel is where adjustments for the Reference Generator, Feedback Generator, and Force Observer are made (the term "observer" is control theory terminology for a special-purpose filter that computes a feedback signal)

Access

Open the Observers panel by selecting the Observers option from the **Configuration** menu on the main panel.

When to Use the Panel

Use this panel to do the following:

Reference Generator

- input the cut-off frequency for the lowpass filter used when the command mode is displacement
- input the cut-in and cutoff frequency for the bandpass filter used when the command mode is velocity
- input the cut-in frequency for the highpass filter used when the command mode is acceleration

Feedback Generator

- input the crossover frequency

The velocity feedback signal is generated from either the position feedback or the acceleration feedback. At lower frequencies, the position feedback is used. At higher frequencies, the acceleration feedback is used. The crossover frequency, where the source of generation is switched from position to acceleration, can be adjusted.

Force Observer

- set the cutoff frequency of the lowpass filter

Observers (continued)

Control Descriptions

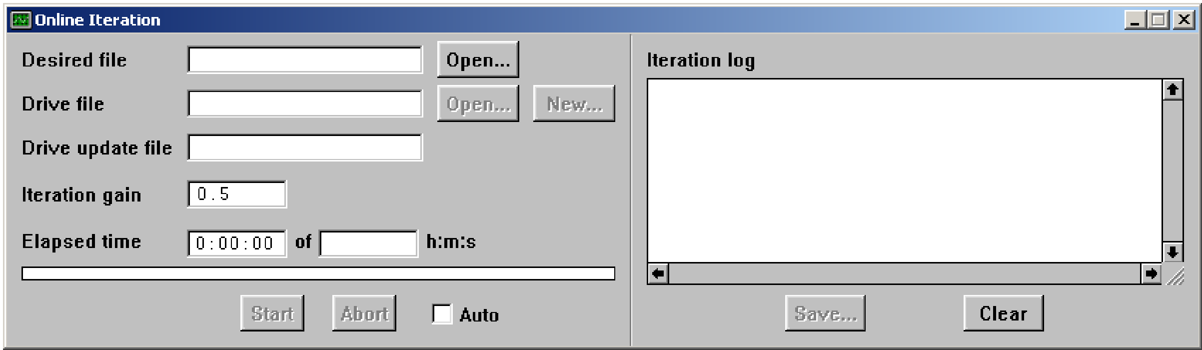
Control	Description
Reference generator:	
Cut-in frequency slide bar and text box	Input the cut-in frequency for the bandpass filter (velocity mode) or the highpass filter (acceleration mode). Valid only in velocity and acceleration control modes, this is the frequency below which energy content in the reference signal is removed to prevent large commanded displacement. Because reference signals (such as earthquake records) differ on low frequency content, you may have to adjust this frequency often on a per-test basis. A lower value is better because less frequency content is removed from your reference signal, which results in improved reference-feedback matching. Physical displacement limits place a lower bound on this frequency. For sine waves, the amount of displacement amplitude X that can be expected given acceleration amplitude A can be computed from the formula $X = A/(2\pi f)^2$. Discontinuities in the derivatives of the reference signal also place a lower bound on this frequency, because the highpass filter acts as a double differentiator at low frequencies, greatly amplifying derivative discontinuities that emerge as large transients in the Displacement Reference. You can determine whether the cut-in frequency is high enough for your reference signal to prevent these problems by using the Preview feature available on the Main Panel, which allows you to play out a reference waveform and observe the Reference Generator outputs without actually moving the system. Use the Digital Meter's Max/Min displays to view the range of excursion of the displacement reference signal; if it exceeds the physical displacement limits, the cut-in frequency must be increased. Keep in mind that the filter is only second order and therefore makes a gradual transition between passband and stopband. Therefore a significant amount of signal energy below the cut-in frequency will leak through the filter.

Observers (continued)

Control Descriptions

Control	Description
Cutoff frequency slide bar and text box	Input the cutoff frequency for the lowpass filter (displacement mode) or for the bandpass filter (velocity mode). Valid only in displacement and velocity control modes, this is the cutoff frequency of the lowpass filter and bandpass filter, respectively.
Feedback generator : **Crossover frequency** slide bar and text box	Input the crossover frequency where the predominate feedback sensor is switched from position (LVDT) to acceleration. This is the frequency below which the displacement sensor has maximum influence on the computed feedbacks, and above which the acceleration sensor has maximum influence. You should leave this at the default value of 1.0 Hz. Use EXTREME CAUTION if changing this parameter. Normally it should not have to change once the system is installed.
Force observer: **Cutoff frequency** slide bar and text box	Input the cutoff frequency for the force feedback lowpass filter. This is the cutoff frequency of a lowpass filter applied to the force feedback. Normally you can leave this at the default value of 1000 Hz, which means no filtering (any value above 512 Hz turns off the filter). Lowering the cutoff frequency may improve control quality in systems where the force feedback appears excessively noisy, but lowering it too far will introduce too much phase lag that will render the force feedback incapable of suppressing the oil column resonance.

Online Iteration



Panel Description

Online Iteration (OLI) is a control technique that repeatedly modifies the command input to a control system on an individual sample-by-sample basis until the control system response is almost a perfect replica of the original desired command.

The Online Iteration panel allows you to set up and run online iteration, including the following tasks:

- Select and open a desired file
- Select and open or create a drive file
- Set the iteration gain
- Start manually, start automatically, or abort online iteration
- Monitor the process in an iteration log, and save this log. Notice that this log is editable, so you can add comments.

Access

Open the Online Iteration panel by selecting the **Controllers** option from the **Operation** menu on the main panel, then dragging right to open the Controllers menu, and selecting **Online Iteration**. You can also open this panel by clicking on the **OLI** icon on the Main panel.

When to Use the Panel

Use this panel when basic adaptive inverse control alone does not remove the tracking error because of nonlinearities. For example, nonlinearities arise in mixed mode applications, where the drive signal is of one type (stroke) and the response of another (acceleration).

NOTE *Online iteration is turned on or off using the Adaptive Control button OLI on the main panel.*

*Enabling OLI will automatically put AIC into **Frozen** mode since online iteration requires adaptive iteration control be enabled before it can run.*

Online Iteration (continued)

Control Descriptions

Control	Description
Desired file text box and **Open...** button	Selects a desired time history file. You will be prompted with a file open dialog box.
Drive file text box, and **New** button	Creates a new drive file sequence. You will be prompted to enter the root name of the drive file sequence with the dialog box.
Drive file text box, **Open** button	Opens an existing drive file. You will be prompted with a file open dialog box.
Drive update file text box	Displays the name of the current drive update file, a new command file generated by online iteration. A new drive update file is generated during every pass. When tracking, the update file from one pass automatically becomes the drive file for the next pass. When frozen, the drive update file is generated, but does not become the drive file for the next iteration. The filename for each update is formed by adding a numeral to the original drive filename extension. For example, a desired file named JTS.DES will generate files named JTS.D00, JTS.D01, and so on.
Iteration gain text box	Sets the rate at which the iterations converge to a final solution. Acceptable values range from zero to one.
Elapsed time text	Displays the elapsed time and the total length of an iteration textually. Elapsed time is also displayed graphically in the progress bar. (see below)
Progress bar	Shows the percent of the current file completed, as a progress bar that grows from left to right.
Start button	Starts the current iteration.
Abort button	Terminates the current iteration prematurely.

Online Iteration (continued)

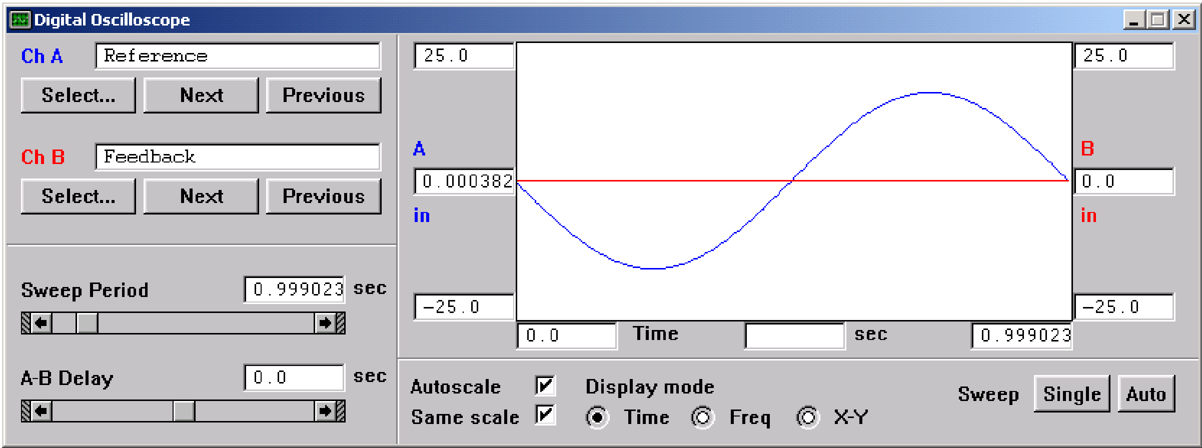
Control Descriptions (continued)

Control	Description
Auto checkbox	Specify automatic iteration mode. When checked, after completion of an iteration, the next iteration is begun immediately without having to press the Start button. If unchecked during an iteration, motion will stop at the end of the current iteration. Do not use this feature unless you have run a few iterations manually and are confident that the iteration process is progressing smoothly.

Iteration log list box	Displays the results of each iteration so that iteration progress can be monitored. A typical iteration log entry looks like this:
	`Iteration 4:       19:53:30 Sat 05-Apr-03`
	`  Desired:          KobeXGee.des`
	`  Drive:            KobeXGee.d04`
	`  Drive update:     KobeXGee.d05`
	`  Iteration gain:   0.8`
	`  Elapsed time:     0:00:58 of 0:00:58`
	`  Response error:   max           rms`
	`    Ch 1:           0.178113      0.006182`
	`  Drive update:     max           rms`
	`    Ch 1:           0.799459      0.092892`

Save button	Saves the text in the iteration log to a text file.
Clear button	Clears the text in the iteration log.

Oscilloscope



Panel Description

The Oscilloscope panel shows oscilloscope traces for one or two signals. This panel allows you to perform the following tasks:

- Select one or two signals to be monitored.
- Set the sweep period and delay for the display of the selected signals.
- Select the scaling mode of the selected signals.
- Select the display mode for the monitor.
- Select the sweep mode for the monitor.

Access

Open the Oscilloscope panel by selecting the Oscilloscope option from the **Display** menu on the main panel.

When to Use the Panel

Use this panel at any time to monitor system signals.

Oscilloscope (continued)

Control Descriptions

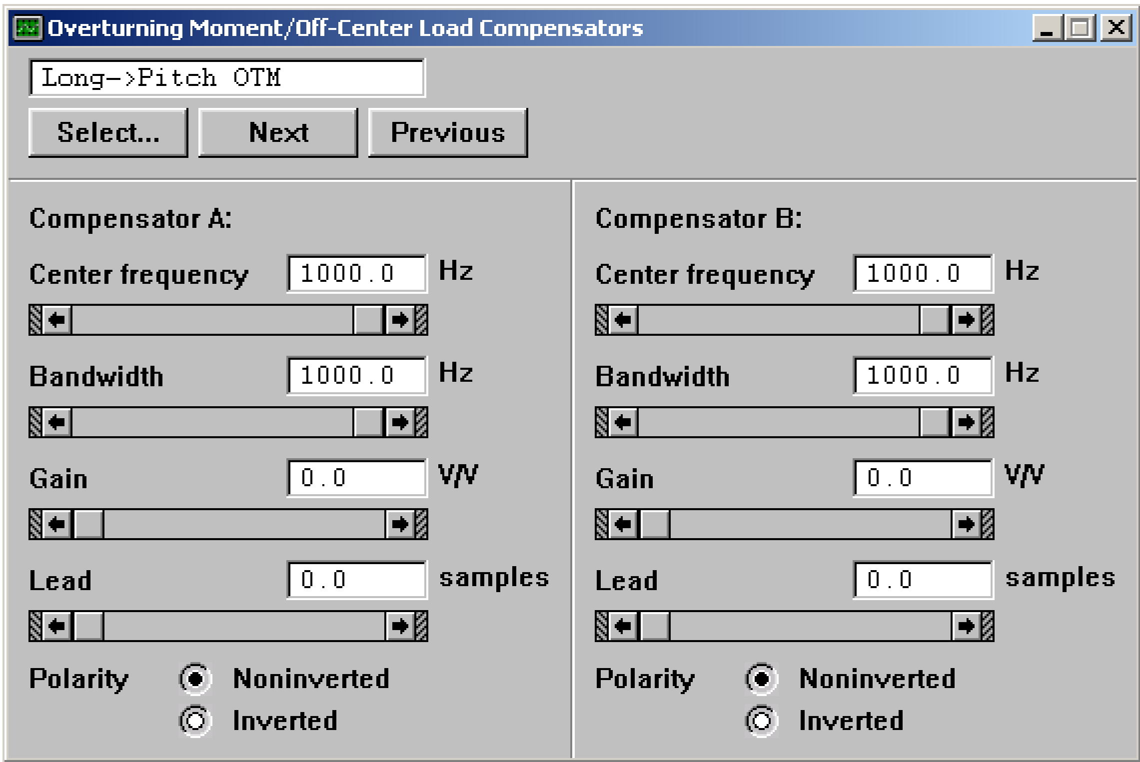
Control	Description
Channels select controls	
Ch A or **Ch B** text box	Shows the name of the currently selected signal. Select a signal using the **Select...**, **Next**, or **Previous** buttons. You can select NONE from the **Select...** list (or a blank from **Next** or **Previous**) to remove a channel from the display.
Select... button	Opens the signal selection list, from which you can select a signal.
Next button	Selects the next signal in the list.
Previous button	Selects the preceding signal in the list.
Sweep Period slide bar and text box	Sets the sweep period in seconds, for a trace on the oscilloscope display. You can use the slide bar to set a value or enter it in the text box.
A–B Delay slide bar and text box	Sets the time by which the Channel B trace follows the Channel A trace. (If the value is negative, B precedes A.) You can use the slide bar to set a value or enter it in the text box.
Autoscale check box	Selects independent autoscaling. In this mode, the two signals are scaled to fill the entire scope display area, regardless of their relation to each other.
Same scale check box	If this box is checked, the same scaling is applied to both signals.
Display mode radio buttons	Select a relation for the A and B traces: **Time** time is displayed along the X axis, amplitude along the Y axis **Freq** frequency is displayed along the X axis, amplitude along the Y axis **X–Y** signal A amplitude is displayed along the X axis, signal B amplitude along the Y axis

Oscilloscope (continued)

Control Descriptions (continued)

Control	Description
Scope display area text boxes	The text boxes surrounding the scope display area show the values of the upper and lower limits currently displayed. • If in **Time** display mode, the top and bottom text boxes on the right and left sides show the minimum and maximum values of the A and B traces (respectively); the right and left text boxes on the bottom of the monitor show time. • If in **Freq** display mode, the top and bottom text boxes on the right and left sides show the minimum and maximum values of the A and B traces (respectively); the right and left text boxes on the bottom of the monitor show frequency. If in **X–Y** display mode, values of A and B are shown on the left and bottom (respectively), and nothing is displayed in the text boxes on the right. • If you click on a specific point in the scope display area, a line appears, and the corresponding X and Y values will be shown in the text boxes in the right center, bottom center, and left center.
Sweep Single and **Auto** buttons	Select single sweep or automatically updated sweeps for display. • If in **Single** mode, only one sweep will be displayed. To update the display, use the **Single** button again. • If in **Auto** mode, the display will be updated when one sweep period (as set on the **Sweep Period** slide bar) of new data is available. To return to the single mode from the automatic mode, use either the **Single** or **Auto** button.

Overturning Moment/Off-Center Load Compensators



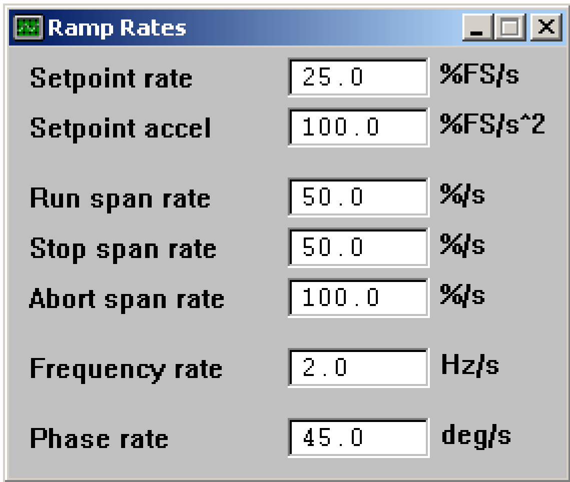
Panel Description	The Overturning Moment/Off-Center Load Compensators panel allows you to setup overturning moment and off-center load cross-coupling notch parameters.
Access	Open the Overturning Moment/Off-Center Load Compensators panel by selecting the **Controller** option from the **Operation** menu on the main panel, then dragging right to open the controllers menu, and then selecting **OTM/OCL Comp**.
When to Use the Panel	You can use the Overturning Moment/Off-Center Load Compensators panel to add notch filters, along with phase and lead for removal of overturning moment or off-center load resonances.

Overturning Moment/Off-Center Load Compensators (continued)

Control Descriptions

Control	Description
Chan text box	Shows the name of the current selected channel. Select a channel using the **Select...**, **Next**, or **Previous** buttons.
Select... button	Opens the channel selection panel, from which you can select a channel.
Next button	Selects the next channel in the selection panel list.
Previous button	Selects the preceding channel in the selection panel list.
Compensator A or B:	
Center Frequency slide bar and text box	Adjusts the center frequency of the notch used to filter the cross-coupling. You can use the slide bar to set a value or enter it in the text box.
Bandwidth slide bar and text box	Adjusts the notch bandwidth (broad or narrow notch). You can use the slide bar to set a value or enter it in the text box.
Gain slide bar and text box	Adjusts the amount of cross-coupling to use. You can use the slide bar to set a value or enter it in the text box.
Lead slide bar and text box	Adjusts the lead-in phase required to compensate the cross-coupling for the system response. You can use the slide bar to set a value or enter it in the text box.
Polarity radio buttons	Selects phase of notch (inverted or noninverted). Because the system phase angle may be less than or greater than 180 degrees, the cross-coupling may have to change sign to be effective.

Ramp Rates



Panel Description

The Ramp Rates panel allows you to set maximum values for the setpoint generator velocity and acceleration, the span ramp rate and phase rate.

Access

Open the Ramp Rates panel by selecting the Ramp Rates option from the **Configuration** menu on the main panel.

When to Use the Panel

Use this panel to set limits on how fast the system can reach the displacement setpoint and how fast it can ramp up or down. Note that these values are % of full scale, not engineering units.

Control Descriptions

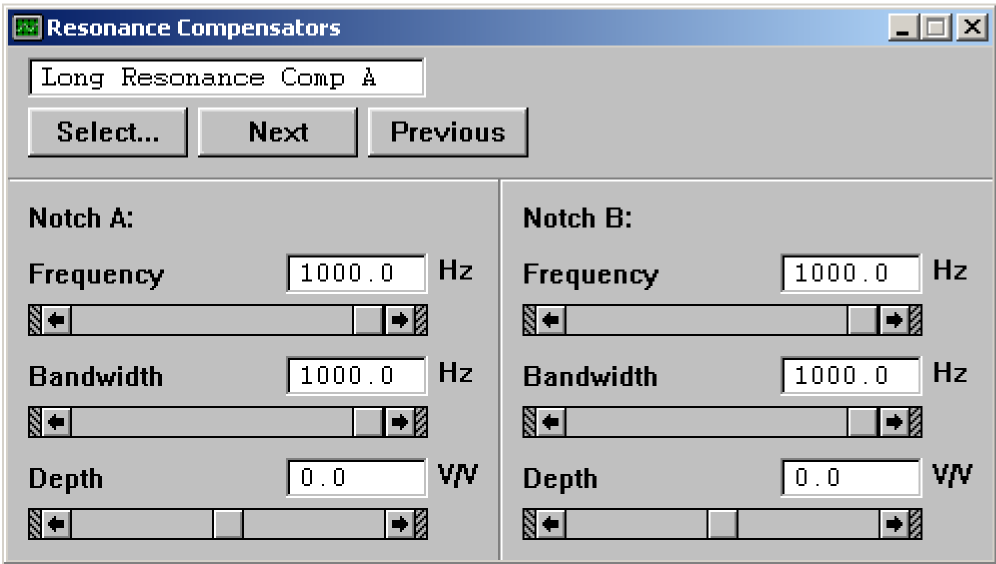
Control	Description
Setpoint rate input	Input the maximum velocity that the system is allowed to achieve while trying to reach the displacement setpoint value set on the main panel.
Setpoint accel input	Input the maximum acceleration the system is allowed to achieve while trying to reach the displacement setpoint value set on the main panel.

Ramp Rates (continued)

Control Descriptions (continued)

Control	Description
Run span rate input	Input the maximum rate that the span function generator is allowed to ramp up when starting a program.
Stop span rate input	Input the maximum rate that the span function generator is allowed to ramp down when stopping a program.
Abort span rate input	Input the maximum rate that the span function generator is allowed to ramp down when aborting a program (abnormal stop). The limit detector will use this rate.
Frequency rate input	Input the rate that the program will ramp to a new frequency when the program cyclic generator frequency is changed.
Phase rate input	Input the rate that the phase lag between a master and slave channel can be changed.

Resonance Compensators



Panel Description

The Resonance Compensators panel allows you to setup the extra TVC notch parameters. The Resonance Compensator consists of four identical notch filters, grouped into two pairs for user interface purposes because resonances usually come in resonance/antiresonance pairs. Like the TVC notch filter, the frequency response of the Resonance Compensator notch filters can be viewed in the FRF Plotter.

Access

Open the Resonance Compensators panel by selecting the **Controllers** option from the **Operation** menu on the main panel, then dragging right to open the Controllers menu, and selecting **Resonance Comp**.

When to Use the Panel

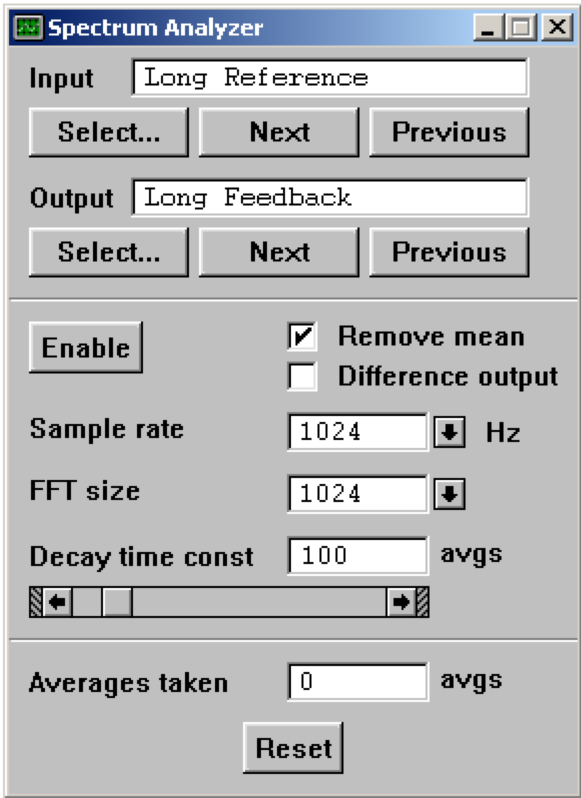
You can use the Resonance Compensators panel to set up or adjust parameters for up to two TVC notches. Notches are used to remove specimen and/or multi-axis system resonances (actuator bowstring).

Resonance Compensators (continued)

Control Descriptions

Control	Description
Chan text box	Shows the name of the current selected channel. Select a channel using the **Select...**, **Next**, or **Previous** buttons.
Select... button	Opens the channel selection panel, from which you can select a channel.
Next button	Selects the next channel in the selection panel list.
Previous button	Selects the preceding channel in the selection panel list.
Notch A or B:	
Frequency slide bar and text box	Adjusts the center frequency of the notch. You can use the slide bar to set a value or enter it in the text box.
Bandwidth slide bar and text box	Adjusts the notch bandwidth (broad or narrow notch). You can use the slide bar to set a value or enter it in the text box.
Depth slide bar and text box	Adjusts how deep the notch extends at the center frequency. The range is 0.0 to -1.0. At 0.0 there is no notch, maximum depth is at -1.0. You can use the slide bar to set a value or enter it in the text box. Note that the notch depth can be greater than 0.0, but great care should be used when trying a positive depth notch as the system may become unstable. Also do not turn on the hydraulics with large positive notch depth values. Return these values to zero, turn on hydraulics, and then slowly return to the positive value.

Spectrum Analyzer



Panel Description

The Spectrum Analyzer panel allows you to set up the spectrum analyzer to measure the forward transfer function between two channels. Use the FRF Plotter panel to display the transfer functions.

Access

Open the Spectrum Analyzer panel by selecting the Spectrum Analyzer option from the **Operation** menu on the main panel.

When to Use the Panel

Use the Spectrum Analyzer when tuning the system to monitor signals for frequency content and to check for system resonances.

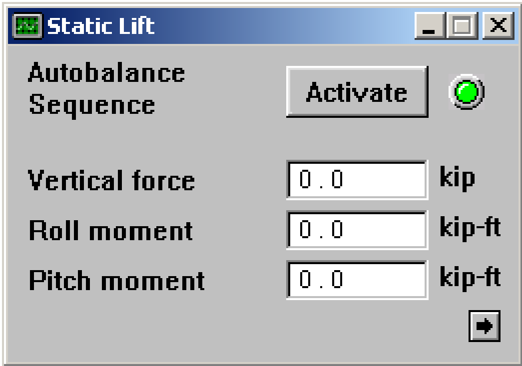
The Spectrum Analyzer produces a true FFT transfer function with input and output PSDs and coherence functions. It uses hanning windows, 50% frame overlaps, and exponential averaging to minimize leverage effects and to smooth spectral estimates.

Spectrum Analyzer (continued)

Control Descriptions

Control	Description
Input and Output text boxes	Shows the name of the selected input channel. Select a channel using the **Select...**, **Next**, or **Previous** buttons.
Select... button	Opens the channel list box, from which you can select a channel.
Next button	Selects the next channel in the list.
Previous button	Selects the preceding channel in the list.
Enable button	Use to enable/disable the spectrum analyzer.
Remove mean check box	When checked, removes the dc content of the signal by adding a hi-pass filter (with an extremely low cut-in frequency) to the input of the analyzer.
Difference output check box	When checked, the software will differentiate the output signal to remove any integrator between the input and output.
Sample rate selection box	Use to select the desired sample rate of the spectrum analyzer.
FFT size selection box	Use to select the FFT size. The FFT size determines the frequency resolution of the analyzer (Resolution = Sample Rate ÷ FFT size).
Decay time constant slide bar and text box	Use to adjust the decay time constant which determines how long the analyzer keeps data before discounting it. A lower average will allow the analyzer to track better but spectral estimates will be noisier.
Averages taken display box	Displays how many averages have been taken by the analyzer. Can be reset to zero using the Reset button.
Reset button	Use to reset the averaging process.

Static Lift



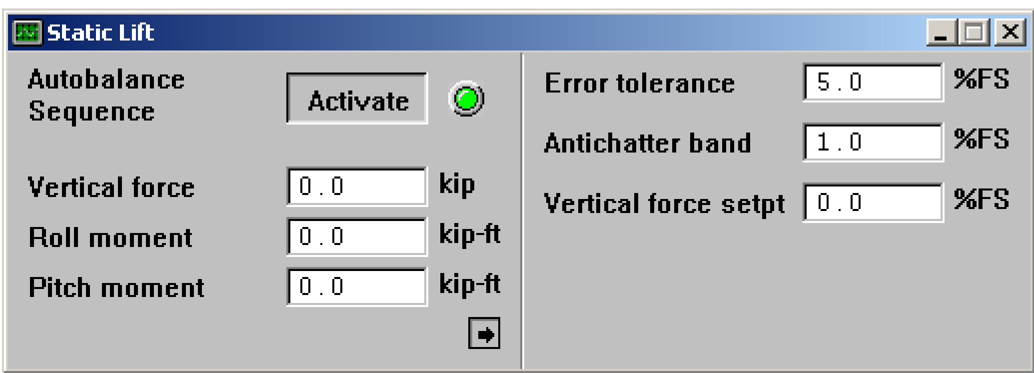
Panel Description

Static Lift panel allows you to run and monitor the static support system.

Access

Open the Static Lift panel by selecting the **Static Lift** option from the **Operation** menu on the main panel.

Toggle the arrow to display the right side of the Static Lift panel as shown below:



When to Use the Panel

Use this panel to raise and lower static support pressure prior to running a test.

Control Descriptions

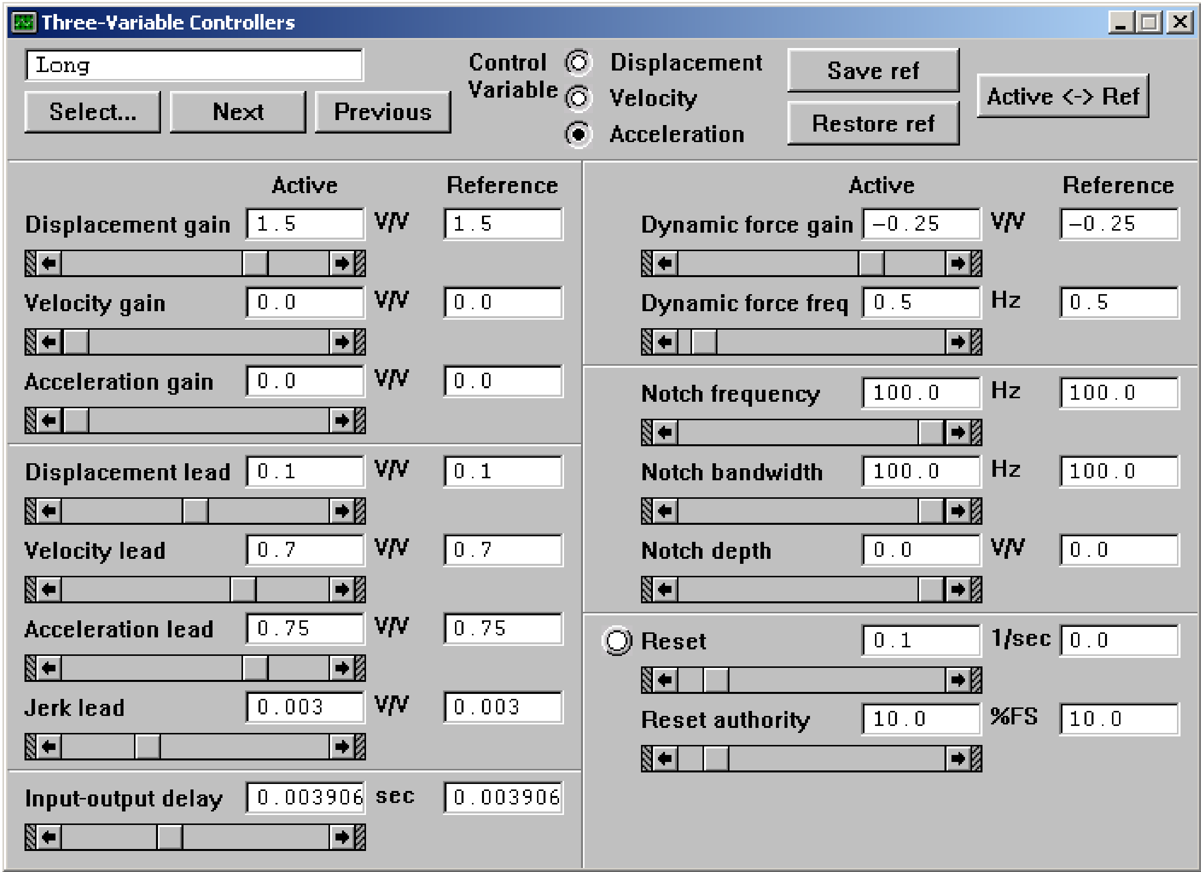
Control	Description
Autobalance Sequence Activate button and indictor light	Press to activate the static lift autobalance sequence. Indicator lights mean the following: Whilte – OFF Yellow – balancing and not at target force Green – static lift is complete and at target force levels Depress to disable the static lift.

Static Lift

Control Descriptions

Control	Description
Vertical force display box	Displays current vertical force feedback. When static support is properly adjusted, this feedback is zero.
Roll moment display box	Displays current roll moment feedback. When static support is properly adjusted, this feedback is zero.
Pitch moment display box	Displays current pitch moment feedback. When static support is properly adjusted, this feedback is zero.
arrow	Toggle the arrow to open/close the right side of the display panel that contains the options described below.
Error tolerance text box	Input the maximum level of error tolerance around the setpoint force level. In general, error tolerance should be greater than antichatter band.
Antichatter band text box	Input the maximum chatter band around the setpoint force level. If levels go outside this band, controlling will restart.
Vertical force setpt text box	Input the vertical force setpoint level.

Three-Variable Controller



Panel Description

The Three-Variable Controller panel allows you to set up and tune the three variable servo control loop. All current and reference gains are included in the parameters saved to a settings file.

Access

Open the Three-Variable Controller panel by selecting the **Controllers** option from the **Operation** menu on the main panel, then dragging right to open the Controllers menu, and selecting **Three-Variable**.

When to Use the Panel

You can use the Three-Variable Controller panel to set up or adjust parameters for a TVC controller, including the following:

- Control variable
- Gains
- Lead values (feedforward)
- Input-output delay
- Dynamic Force
- Notch parameters
- Reset

A notch can be added to the controller to suppress excitation of the oil column. You can view the frequency response of the notch using the FRF panel.

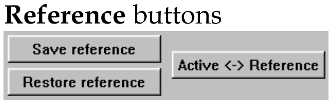
Three-Variable Controller (continued)

Before making any adjustments, you may wish to use the **Active <--> Reference** button to copy the current stable settings to the reference boxes. If the system becomes unstable, you can immediately click on this button again and restore these stable settings to the active boxes. You can then examine the gains that caused the instability.

Background Information

Each of the controls on the Three-Variable Controller panel affects the system in a distinct way. It is important to understand these effects before attempting to tune the system. Refer to Chapter 3, Understanding Control Principles, for more detailed information about the control system and servo control adjustments.

Control Descriptions

Control	Description
Chan text box	Shows the name of the current selected channel. Select a channel using the **Select...**, **Next**, or **Previous** buttons.
Select... button	Opens the channel selection panel, from which you can select a channel.
Next button	Selects the next channel in the selection panel list.
Previous button	Selects the preceding channel in the selection panel list.
Control Variable radio buttons	Selects the control variable. The choices are: Displacement Velocity Acceleration In multichannel systems, the selected control mode is applied to all channels, not just the channel displayed in the panel.
Save/Restore/Switch Reference buttons 	"**Save Reference** Gains" copies the active gain values to the reference gain display boxes; "**Restore Reference** Gains" copies the reference gain values back into the active gain slider bars; "**Active <-> Reference**" swaps active and reference gains. Use the **Save** button to temporarily store a set of gains that you deem satisfactory but wish to improve. If subsequent tuning yields worse results, you can then use the **Restore** button to get back the original "good" gains. If you have two sets of satisfactory gains but wish to see which one is better, you can quickly switch between the two using the Switch button. The Restore and Switch buttons are inactive when the program waveform is running because sudden gain changes while the system is in motion can result in large transients.

Three-Variable Controller (continued)

Control Descriptions

Control	Description
	The following parameters are explained in more detail in Chapter 3. Chapter 6 explains how the parameters are used in tuning the servo loop.
Displacement Gain slide bar and text box	Adjusts the gain applied to the displacement error. This is the primary feedback gain used in TVC. You can use the slide bar to set a value or enter it in the text box.
Velocity Gain slider bar and text box	Adjusts the gain applied to the velocity feedback. This gain is seldom if ever used. You can use the slide bar to set a value or enter it in the text box.
Acceleration Gain slide bar and text box	Adjusts the gain applied to the acceleration feedback. This gain is seldom if ever used. You can use the slide bar to set a value or enter it in the text box.
Displacement Gain slide bar and text box	Adjusts the gain applied to the displacement reference. It affects response at very low frequencies. This gain is seldom if ever used. You can use the slide bar to set a value or enter it in the text box.
Velocity Lead slide bar and text box	Adjusts the gain applied to the velocity reference. It affects response at frequencies below the oil column natural frequency. This is the primary feedforward gain used in TVC. You can use the slide bar to set a value or enter it in the text box.
Acceleration Lead slide bar and text box	Adjusts the gain applied to the acceleration reference. It affects response at frequencies near the oil column natural frequency. You can use the slide bar to set a value or enter it in the text box.
Jerk Lead slide bar and text box	Adjusts the gain applied to the derivative of the acceleration reference. It affects response at frequencies above the oil column natural frequency. You can use the slide bar to set a value or enter it in the text box.
Input-output delay slide bar and text box	Adjusts the amount of delay applied to the reference in order to align it with the feedback for display and error calculation purposes. You can use the slide bar to set a value or enter it in the text box.

Three-Variable Controller (continued)

Control Descriptions

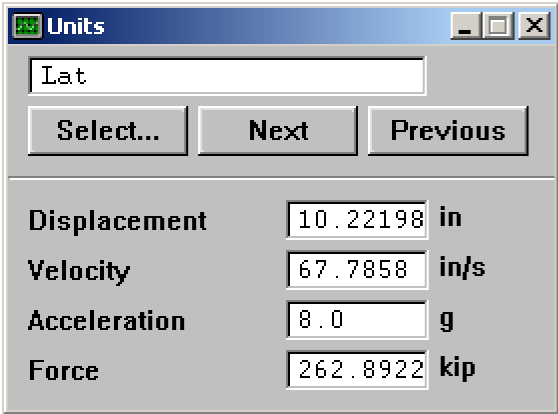
Control	Description
Dynamic Force Gain slide bar and text box	Adjusts the gain applied to the dynamic force feedback, which is a highpassed version of the regular force feedback. It provides damping of the oil column resonance. You can use the slide bar to set a value or enter it in the text box.
Dynamic Force Frequency slide bar and text box	Adjusts the cut-in frequency of the highpass filter applied to the force feedback. A value of 0.5 to 1.0 Hz is recommend for most systems. You can use the slide bar to set a value or enter it in the text box.
Notch Frequency slide bar and text box	Adjusts the center frequency of the notch filter applied to the controller output. Use a value equal to the frequency of resonance that you are trying to compensate. You can use the slide bar to set a value or enter it in the text box. To aid tuning, the frequency response of the TVC notch filter can be viewed in the FRF Plotter.
Notch Bandwidth slide bar and text box	Adjusts the 3dB bandwidth of the notch filter applied to the controller output. Use a value equal to the bandwidth of resonance that you are trying to compensate. You can use the slide bar to set a value or enter it in the text box.
Notch Depth slide bar and text box	Adjusts the depth of the notch filter applied to the controller output. Use a negative value to suppress a resonance, a positive value to boost an antiresonance, and a zero value to do nothing. You can use the slide bar to set a value or enter it in the text box.

Three-Variable Controller (continued)

Control Descriptions

Control	Description
Reset Integrator Gain text box and slide bar	Adjusts the time constant of the reset integrator used to remove static offsets in the system. You can use the slide bar to set a value or enter it in the text box.
Reset indicator	Displays the current state of the reset integration process using this color code: • **White**: The reset integrator is off. • **Green**: The reset integrator is integrating ("tracking") and its contribution to the controller output is less than the Maximum Authority limit. • **Red**: The reset integrator is on but its output is pegged at the Maximum Authority limit (plus or minus). The conditions for tracking are: • Hydraulics are on and in high pressure. • The system is at rest. • The reset gain is greater than zero.
Reset Integrator Maximum **Authority** text box and slide bar	Adjusts the maximum amount of correction that reset integrator is allowed to apply to the controller output. You can use the slide bar to set a value or enter it in the text box. Note that **Reset** is active only when the program is stopped.

Units



Panel Description The Units panel displays the system full scale units.

Access Open the Units panel by selecting the **Units** option from the **Configuration** menu on the main panel.

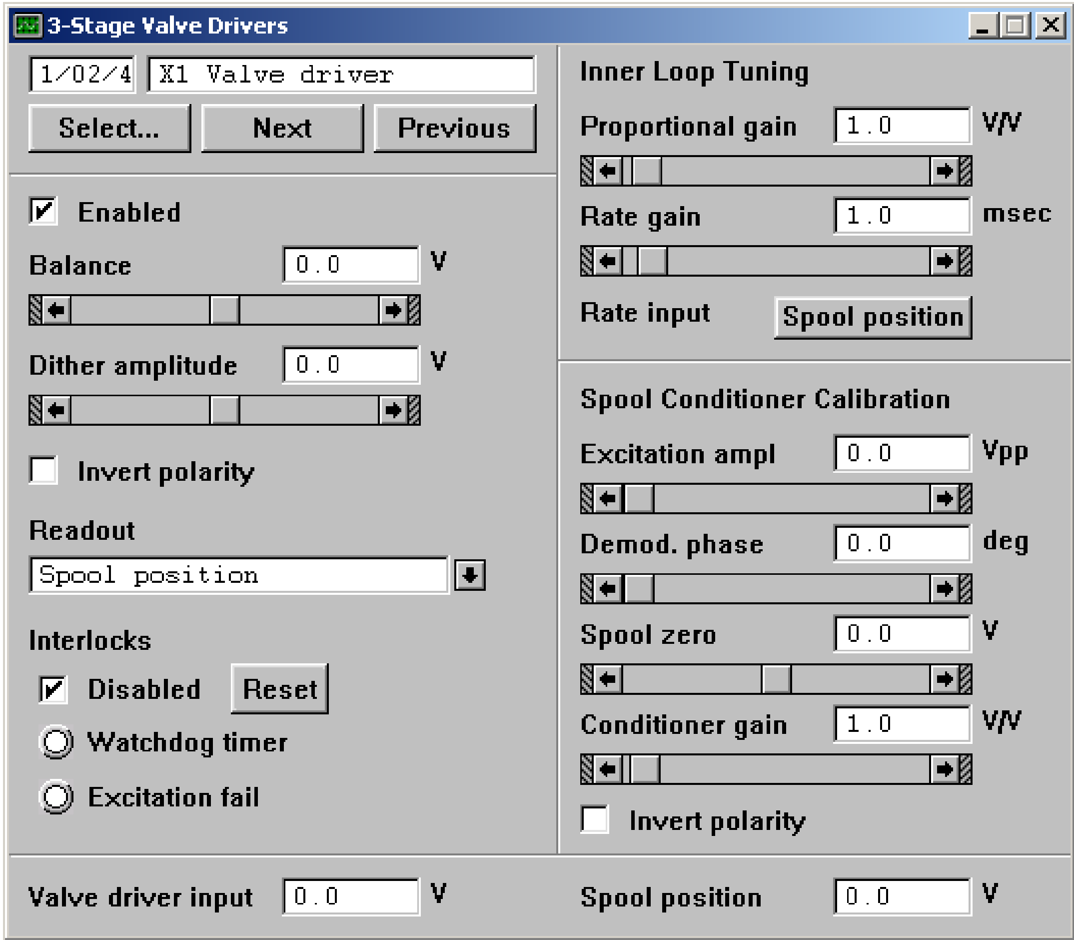
When to Use the Panel This panel displays the full-scale units for system feedback signals.

You can use this panel to determine scaling for BNC inputs and outputs, and when using the external analog program option.

Control Descriptions

Control	Description
Channel text box	Shows the name of the current selected channel. Select a channel using the **Select...**, **Next**, or **Previous** buttons.
Select... button	Opens the channel selection panel, from which you can select a channel.
Next button	Selects the next channel in the selection panel list.
Previous button	Selects the preceding channel in the selection panel list.
Displacement display box	Displays the full scale value for displacement.
Velocity display box	Displays the full scale value for velocity.
Acceleration display box	Displays the full scale value for acceleration.
Force display box	Displays the full scale value for force.

Valve Drivers



Panel Description

For three-stage valves, the Valve Drivers panel allows you to perform the following tasks:

- Select a specific valve driver channels
- Adjust the dither amplitude and balance for the selected valve driver channel
- View the value input to the valve driver by the servocontroller
- Insert the valve phase
- Disable and/or reset interlocks
- Monitor interlocks
- Tune the inner loop
- Make spool conditioner adjustments

Access

Open the Valve Drivers panel by selecting the **Valve Drivers** option from the **Calibration** menu on the main panel.

When to Use the Panel

Use the Valve Drivers panel when adjusting the valve balance and dither amplitude during test setup. If three-stage valves are being used, the Valve Drivers panel also allows you to tune the inner loop and make spool conditioner adjustments.

Valve Drivers (continued)

Control Descriptions

Control	Description
Driver text box	Shows the name of the selected valve driver. The adjacent driver ID box shows the chassis location, slot location, and channel of the selected driver. Select a channel using the **Select...**, **Next**, or **Previous** buttons.
Select... button	Opens the valve driver list box, from which you can select a channel.
Next button	Selects the next valve driver in the list.
Previous button	Selects the preceding valve driver in the list.
Enabled check box	When checked, sets input of valve driver to zero. (For tuning purposes only).
Balance slide bar and text box	Adjusts the electrical balance of the servovalve.
Dither amplitude slide bar and text box	Adjusts the dither applied to the servovalve. You can use the slide bar to set a value or enter it in the text box.
Invert polarity check box	Selects inverted or non-inverted valve phasing.
Readout pop-up menu	Selects a function for direct readout. The choices are: • Valve current • Spool command • Demodulator filter input • Spool zero output • Spool position • Preamplifier output • Post-gain amplifier out • 5 Volt reference
Interlocks **Disabled** check box	When checked, disables hardware interlocks for the selected channel.
Reset button	When pressed, resets the hardware interlocks for the selected channel.
Watchdog Timer indicator	Indicates the status of the watchdog timer.
Excitation fail indicator	Shows whether excitation has failed. This detector is always enabled, both in hardware and software. Excitation failure causes a system interlock because it may indicate a broken, defective or missing conditioner cable.

Valve Drivers (continued)

Control Descriptions (continued)

Control	Description
Inner Loop Tuning	These adjustments are for three-stage valves only.
Proportional gain slide bar and text box	Adjusts the proportional gain for the selected valve driver. You can use the slide bar to set a value or enter it in the text box.
Rate gain slide bar and text box	Adjusts the derivative rate gain for the selected valve driver. You can use the slide bar to set a value or enter it in the text box.
Rate input radio buttons	Sets the signal source for rate input as spool position or spool.
Spool Conditioner Calibration	
Excitation amplitude slide bar and text box	Sets the level of the excitation signal sent to the transducer. You can use the slide bar to set a value or enter it in the text box.
Demode. phase slide bar and text box	Sets the demodulator phase of the conditioner output. You can use the slide bar to set a value or enter it in the text box.
Spool zero slide bar and text box	Sets the spool position zero offset. You can use the slide bar to set a value or enter it in the text box.
Conditioner gain slide bar and text box	Adjusts the conditioner gain for the selected valve driver. You can use the slide bar to set a value or enter it in the text box.
Invert polarity check box	Selects inverted or non-inverted spool conditioner polarity.
Valve driver input display box	Shows current value input to the valve driver by the servocontroller. Not editable.
Spool position display box	Displays the current spool position.

Section 6

Operation

The complex nature of a test system requires that the operator be familiar with all aspects of the mechanical and electrical components of the system prior to performing any of the following operating procedures. MTS recommends that the mechanical and electrical component descriptions in the User's Manual and the system Reference Manual be studied and thoroughly understood prior to operating the system.

This section contains the most commonly used operating procedures. These procedures should serve as a guideline and reminder of the critical adjustments and checks to be made for each operation. Execution of these procedures requires that the operator be familiar with the reason for the adjustment as well as the method of adjustment. The operating procedures detailed here are:

- Pre-Test Adjustments
- Hydraulic Turn On
- Test Execution Procedure
- Test Execution Procedure using STEX
- Table Relocation
- Limit Switch Adjustment Procedure
- Hydraulic Shutdown
- Emergency Shutdown
- Using Adaptive Control

As familiarity with the system is gained, these procedures can be altered to suit specific test requirements.

WARNING

The test system is capable of causing personal injury and damage to the test specimen and/or test facility.

Injury or damage can result from attempting to operate the system and disregarding system safety precautions, warnings, and cautions.

It is imperative that you read and understand all safety precautions and procedures before attempting to operate this test system.

Pre-Test Adjustments

Before applying hydraulic pressure, complete the following adjustments.

Specimen Preparation

- Securely mount the test or dummy specimen
- Attach the specimen transducers and cables (if applicable)
- Calibrate the specimen transducers (if required)
- If you are also running the structural test system, ensure that the actuators are securely mounted or positioned.

Activate the Hydraulic Control System

Turn on electrical power to the Hydraulic PC computer. After the PC has completed booting, turn on the hydraulic controller and then wait one minute before double clicking on the Hpc.exe located on your PC desktop.

- hpc.exe

The default Settings file, Settings.set, will be loaded and the main panel will appear.

If Settings.set does not exist, you will be prompted for a settings file.

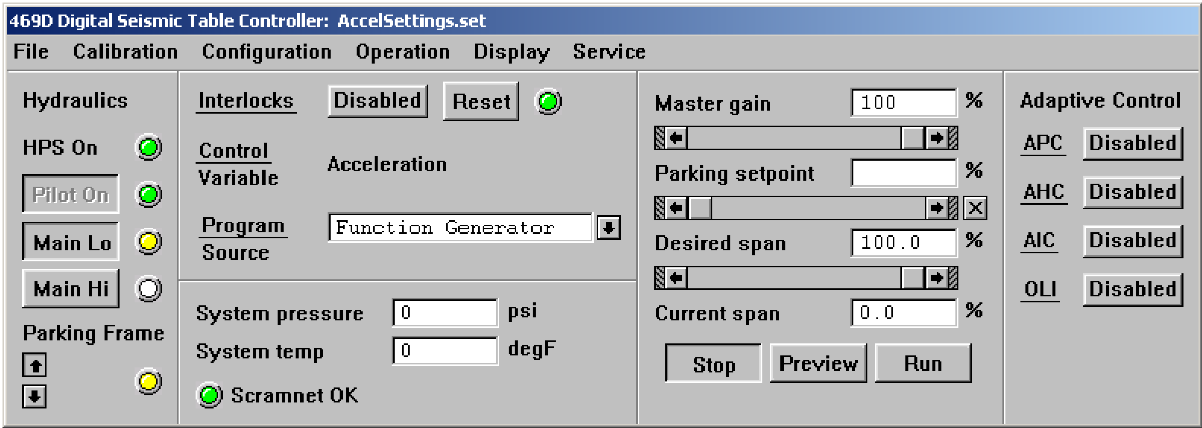
***Note**: When quitting the application, you must wait one minute before restarting the application.*

Activate the Table Control System

Turn on electrical power to the PC computer. After the PC has completed booting, turn on the 469D controller and then wait one minute before double clicking on the 469D.exe Icon located on your PC desktop.

- 469D.exe

The calibration parameters and default Settings file, *Settings.set*, will be loaded and the main panel will appear.



Initial Test Parameter Adjustments

Restore Controller settings, if necessary.

If you wish to use a settings file that you have saved earlier, use the Restore Settings option under the File menu. This option restores all settings except the following:

PARAMETER	DISPOSITION
Transient values (such as the current value of a program)	Not saved or restored
Display/View menu value (such as oscilloscope or digital meter)	Not saved or restored
Message log	Not saved in Settings file (message log has its own file)
Access privilege	Always set to BASIC
Displ setpoint	Always set to 0%
Limits	Always disabled
Hydraulics	Always off
Stop /Run button	Always Stop
Adaptive Control	Always disabled

The HSMs must be off before you can you save settings, restore settings, or quit the application. Note that you can perform these functions when the HPS is on.

Select the 469D Program Source

Select the Program source on the **469D Main Panel**.

- If **Function Generator** is selected, use the Function Generators panel under the Operation menu to set up the parameters.
- If **Data Player File** is selected, use the Data Player panel under the Operation menu to choose the playout file.
- If **Remote Application** is selected, make sure an Ethernet connection exists to the Remote Application (i.e. STEX).
- If **External (Scramnet)** is selected, make sure an external connection is made to a data playout system via scramnet.
- If **Table 1 or 2** is selected, make sure an external connection is made to the other table via scramnet.

Readout Adjustments

Setup and enable the desired readout devices for the 469D Table controller using the **Display** menu.

System Limit Adjustments

- Adjust limit detector levels.
  - Use the **Limit Detectors** panel under the Operation menu to set limit detector levels that ensure the safety of the system components.
- Disable the limit detectors.
  - Select the **(Limits) Disabled** button on the main panel.

Table Hydraulic Turn On Procedure

Complete the following adjustments to ensure a safe start-up of the test system.

Final Safety Checks

- Read the operating safety practices detailed in Section 2 of this manual.
- Verify the Pre-test adjustments made in the preceding subsection.

Interlocks

- Reset any interlocks generated during test setup procedures.

  Click on the Interlocks **Reset** button to clear interlock and limit detection indicators.

  If the **Interlock** indicator does not clear, a hardware interlock or a software limit remains uncleared in the system.

  <u>If you suspect a hardware interlock:</u>

  a. Check the **AC/DC Conditioner** panel to see if a red fault indicator has been set. If a fault has occurred, select the correct conditioner, move the limits outside of the current signal value, and press the Conditioners **Reset** button.

  b. Press the main panel (**Interlock**) **Reset** button to clear the hardware interlock indicators.

  <u>If you suspect a software limit detector is set:</u>

  a. Open the Message Log panel from the **Display** menu to see if a software limit detector remains uncleared. The message will identify the limit.

  b. Open the Limit Detectors panel from the **Operation** menu, and select the associated signal. Make a note of the limit value. Then, move the limits outside of the current signal value and press the main panel (**Interlock**) **Reset** button to clear the software interlock indicators.

  c. Open the Limit Detectors panel from the **Operation** menu, and set the limit detector you adjusted in step b back to its original value.

- Enable the limit detectors on the main panel.
- Click on the **Stop** button on the main panel to ensure the system is in Stop mode.

Hydraulic Power Start-up

⚠ WARNING

Actuator movement may occur when the **HPS On** button is pressed. Actuator movement can result in injury to personnel or damage to the specimen.

Ensure that all personnel are clear of the actuator(s) or fixturing before pressing the HPS On button

On the **Hydraulic Power Controller Main Panel**, do the following:

- Select the desired accumulators.
- Press the appropriate **HPS On** buttons to turn on the selected HPUs. The indicator will flash yellow. The HPS On indicator will turn green when high pressure is achieved.

Table Hydraulic Start-up

⚠ WARNING

Actuator movement may occur when the **Main Lo** button is pressed. Actuator movement can result in injury to personnel or damage to the specimen.

Ensure that all personnel are clear of the actuator(s) or fixturing before pressing the Main Lo button

On the **469D Digital Seismic Table Controller Main Panel**, do the following:

- Click on the **Pilot On** button on the main panel. The indicator will turn green, and the Main Lo button on the main panel will be enabled.
- Click on the **Main Lo** button on the main panel to apply low hydraulic pressure to the actuators. The Main Lo indicator will turn yellow.
- Allow the system HSM to run at low pressure until the normal hydraulic fluid operating temperature is achieved (at or above 32° C). Monitor the hydraulic fluid operating temperature using the temperature panel located on the controller.

Note *Optimum system response is achieved when the hydraulic fluid is at its normal operating temperature (at or above 32° C).*

- Verify the gain settings for stable system control. Decrease the **Master Gain** control on the main panel, if necessary.
- Set the displacement **Parking Setpoint** control on the main panel to midstroke or to the desired test startup position.
- Ensure parking frame is in the down position before going to high pressure.
- Click on the **Main Hi** button on the main panel to apply high hydraulic pressure to the actuators. The Main Hi indicator will turn green.

Note *It is safer and more efficient to use low pressure until high pressure is necessary.*

- Press the **Activate** button on the **Static Lift** panel (Operation→Static Lift) to activate the static lift.
- After autobalancing sequence is complete, disable the static lift by pressing the **Activate** button on the **Static Lift** panel.

Table Test Execution Procedure (except Remote Application Mode)

After applying hydraulic pressure to the actuators, complete the following procedure to execute a test. Refer to the following section for test execution procedures for remote application (i.e. STEX) mode tests.

Verification and Safety Checks

Note *Optimum system response is achieved when the hydraulic fluid is at its normal operating temperature.*

- Ensure that the hydraulic system is at its normal operating temperature (at or above 32° C) before proceeding with testing.
- Check the program input and pre-test adjustments completed in the preceding subsections.
- Clear all personnel from the test area.

Starting the Program

CAUTION

When adjusting the SPAN and SETPOINT controls, ensure that the test program does not exceed 100% of the full-scale limits.

The SPAN and SETPOINT controls can cause the program to exceed 100% of the system full-scale limits.

If the program exceeds 100% of full-scale, the limit detector interlocks will activate causing a program interlock. A program interlock may invalidate the test data because the test will stop abruptly.

- Verify that the **Desired Span** control (program amplitude) on the main panel is set to a known safe operating level or 0%.
- Verify the program source selection and parameters.
- If desired, enable Adaptive Control. Refer to the Section, **Using Adaptive Control,** for information on how to determine which

adaptive control function(s) to use, parameter adjustments, and enabling procedures. If you didn't restore a settings file or this is the first time you are enabling adaptive control, you may need to run a training session first (for AHC, AIC, and OLI).

WARNING

Immediate and unexpected actuator response is possible when a Run command is applied to the system.

Unexpected actuator response can result in personal injury or equipment damage.

Clear all personnel from the test system before running a test.

- Press the **Run** button on the main panel to begin the test.

Adjustments During a Test

- Make adjustments to the readout devices as desired.
- Minor adjustments to the **Desired Span** control can be made at this time.
- While constantly checking for system stability, slowly adjust the main panel **Desired Span** control towards 100%.
- If the system becomes unstable, immediately remove hydraulic pressure by pressing the **EMERGENCY STOP** button. Identify the cause(s) of the instability before attempting the test again.

Stopping a Test

- If any of the Adaptive Control functions are set to Tracking, put them into **Frozen** mode.
- Click on the **Stop** button on the main panel to stop the test.

Test Execution Procedure (using STEX Remote Application Mode)

The Remote Application Mode is used as an automated file play-out and data recording method. When you select Remote Application as the program source, only the Run/Stop buttons on the main panel are available.

STEX generates the drive record prior to the test. After the test, STEX collects the response data from the controller.

The operator starts the play-out by pushing the Start button on the STEX application window, and then pushing the RUN button on the controller.

Prior to the play-out, the controller reads the drive record (generated by STEX) and checks to ensure the data matches configuration of the system (i.e. DOF, control mode, and units).

After applying hydraulic pressure to the actuators, complete the following procedure to execute a STEX test.

Verification and Safety Checks

***NOTE**: Optimum system response is achieved when the hydraulic fluid is at its normal operating temperature.*

- Ensure that the hydraulic system is at its normal operating temperature (at or above 32° C) before proceeding with testing.
- Check the program input and pre-test adjustments completed in the preceding subsections.
- Clear all personnel from the test area.

WARNING

Immediate and unexpected actuator response is possible when a Run command is applied to the system.

Unexpected actuator response can result in personal injury or equipment damage.

Clear all personnel from the test system before running a test.

- Push the **RUN** button on the STEX execution panel to begin the test.

The STEX file play-out can be aborted prior to the end-of-file. Either the **Stop** button on the 469D Main Panel or the **Abort** button on the STEX screen can be used to prematurely stop the file play-out.

Table Relocation

Follow these procedures to move Table 1 and/or Table 2 to new position (s). Rollers are provided under the tables for ease of movement.

Disassembly

Preparation

1. Command table to home position, then extend parking frame screw jacks to support table weight in this position. This will help align holes on lift beam to table and horizontal actuator mounting blocks.
2. Sweep/clean trench floor to minimize amount of grit and chips that get embedded in the parking frame wheels.
3. Clean top surface of new vertical and horizontal actuator foundation plates. Remove dirt, oil and grease to leave a clean, dry surface.
4. Remove plastic plugs from tapped holes in new locations (save plugs for old locations). Clean threads as required.
5. Clean tapered diameter in foundation plates for mounting block wedge ring. Apply Molycote to inclined wedge surface.

Parking Frame

1. Remove shims underneath parking frame corners so weight is on wheels. The hydraulic jack can be placed under bottom 1.5 inch thick plate in each corner of parking frame.
2. Remove locating pin to guide rail on each side of parking frame.

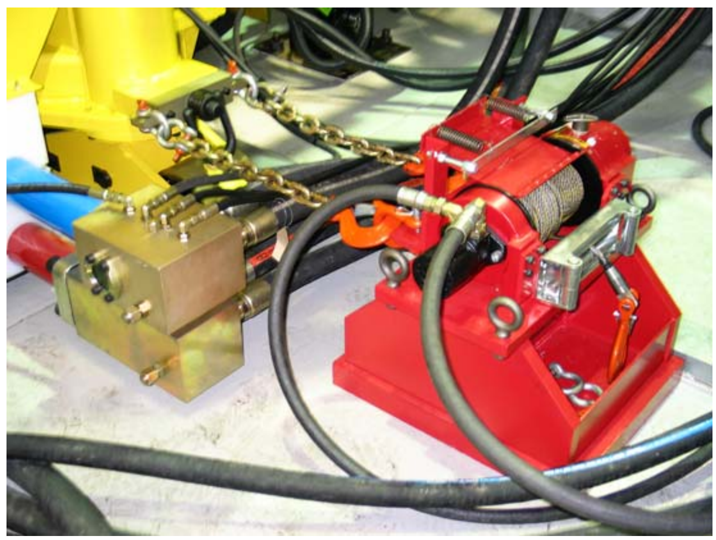
Vertical Actuators

1. Loosen 1”-8 UNC cap screws attaching base swivels to foundation plate. Screws can stay in swivel jaws.
2. Place blocking or fixture between actuator base and horizontal tube on parking frame to prevent actuator from swinging in when swivels lift off the ground (weight of static support bottle causes actuator to rotate about upper swivel).

Horizontal Actuator Mounting Blocks

1. Loosen 1 ¼-7 UNC jam screws (qty 2) on mounting block anti-rotate plate until screw end is flush with side of plate.
2. Loosen all 1 ¼-7 UNC cap screws (qty 12 on perimeter, 1 in center) holding mounting block to foundation plate. Remove screws that will be covered by lift beam.
3. Loosen 1 ¼-7 UNC wedge pusher screws (qty 6 on ring dia) so wedge can be pulled up.
4. Tighten 1-8 UNC cap screws (qty 3) to pull wedge ring up until it disengages from foundation plate.

Winch Assembly



1. If parking frame is moving towards a trench wall, place winch assembly next to that wall with cable hook facing the parking frame. Attach two short chains from winch assembly to wall reaction bar.
2. If parking frame is moving towards the other parking frame, place winch assembly next to the stationary parking with cable hook facing the moving parking frame. Attach two short chains from winch assembly to reaction bar on stationary parking frame. Attach single long chain from opposite side of stationary parking frame to far trench wall, and use chain load binder (tensioner) tool to remove chain slack so stationary frame does not get pulled out of position.
3. Pull up cable release lever on winch gearbox and pull out cable until hook can be attached to hoist ring on moving parking frame.

4. Attach control manifold P&R hoses to -12 ports on distribution manifolds in trench. Attach control manifold A&B hoses to winch motor A&B ports.

Lift Beam Attachment

1. At parking frame control enclosure, turn control selector switch to "local". From the home position, lower parking frame screw jacks 1.75" (measure tube extension with tape measure or monitor vertical actuator feedback) so that top of table is even with top of horizontal mounting blocks.

2. Lower beam diagonally over table so beam holes line up with holes in mounting blocks. Adjust table height with screw jacks until beam rests on both table and mounting blocks.

3. Attach beam to mounting blocks with washer plates (qty 2 each end) and 5/8-11 UNC x 2"L caps crews (qty 2 each plate).

4. Attach beam to table with 1 1/8-7 UNC x 4"L cap screws and washers, qty four total.

Hydraulics

1. Extend parking frame screw jacks until vertical actuator base swivels and horizontal actuator mounting blocks clear foundation plate rods (approx 27" of jack guide rod showing). An electrical limit switch will prevent screw jacks from extending too far.

2. Close all ball valves on parking frame distribution hoses (qty 4).

3. If parking frame distribution hoses must be moved to another manifold, open inlet needle valve on parking frame (on top of control manifold) to relive any pressure trapped in the pressure inlet hoses. Connect transfer pump outlet hose to parking frame drain ball valve and inlet hose to P&R ball valves to remove oil trapped in hoses and parking frame. Disconnect P, R and D distribution hoses from wall manifolds and cap all fittings to prevent leakage and contamination. Make sure caps/plugs are clean and o-rings are in good condition. Torque split flange hose connections to 65 ft lb (1/2-13 UNC, split flange rating).

Moving Table

1. Re-engage winch cable release lever and operate manual directional valve on winch control manifold to pull parking frame towards winch. Hand knob on side of control manifold can be used to adjust winch speed.
2. Watch that hoses don't get caught on foundation plates and actuators and mounting blocks have adequate clearance.
3. Slow down winch when approaching final position and stop when parking frame location pins can thread into guide rail holes. Be careful not to overshoot the final position, moving backwards may be difficult.

Assembly

Fix Parking Frame Position

1. Install locating pin to guide rail on each side of parking frame.

Winch Assembly

1. Pull up cable release lever on winch gearbox to release cable tension or push directional valve lever to "winch out." Disconnect winch cable from parking frame and wind in cable.
2. Remove reaction chains from foundation walls.

Hydraulic Distribution

1. Connect parking frame P, R and D distribution hoses to new distribution manifolds as required. Make sure joint surfaces are clean and o-rings are in good condition.
2. Torque split flange hose connections to 65 ft lb (1/2-13 UNC, split flange rating).

3. Close ball valve at winch P hose and remove winch hoses from distribution manifold. Cap -12 tube fittings.
4. Close inlet needle valve on parking frame to prevent P to R leakage at hose inlet (needle valve is on top of parking frame control manifold).
5. Open P ball valves at distribution manifolds so parking frame screw jacks can be operated.

Vertical Actuators

1. Apply Molycote to base swivel screw threads and underneath the screw head to ensure proper torque value.
2. Lower parking frame screw jacks until swivel screws can be threaded into foundation plate. Once all screws are started, lower jacks until base swivels rest on foundation plate, and then run in screws until snug.
3. Remove blocking between actuator base and parking frame so actuators are free to rotate about base swivels.

Engage Horizontal Actuator Mounting Blocks

1. Apply Molycote to mounting block screw threads and underneath the screw head to ensure proper torque value.
2. Apply Molycote to wedge diameter.
3. Lower mounting blocks with parking frame screw jacks until wedge ring engages pilot diameter in foundation plate. If mounting blocks don't line up to foundation plates, install table hoist rings and attach crane to table (do not lift table using hoist rings on beam!). Support table weight on crane and lower parking frame screw jacks until table is free be moved horizontally. Align mounting blocks to foundation plates and lower table with crane.
4. Engage outer 1 ¼-7 UNC caps crews (qty 12) to hold mounting block to foundation plate.
5. Remove Lift Beam and install any 1 ¼-7 UNC cap screws previously removed from mounting block.
6. Loosen 1"-8 UNC cap screws (qty 3) holding wedge ring to mounting block to allow wedge ring to move down.
7. Evenly snug up 1 ¼-7 UNC wedge pusher screws (qty 6 on ring dia) until mounting block starts to lift off foundation plate. This assures that mounting block is concentric to pilot diameter in foundation plate.

8. Slowly back off wedge pusher screws to lower the mounting block to the foundation plate while keeping the wedge surfaces snug and concentric.

9. When bottom of mounting block is resting on foundation plate, back off pusher screws a little more to ensure all weight is on bottom surface of block, then snug up center and all outer perimeter 1 ¼-7 UNC cap screws (qty 1+12).

Shim Parking Frame

1. Install shim plates underneath parking frame corners so weight is off wheels (wheels spin freely). This will unload the wheel bearings and prevent flat spots from temporarily forming on the wheel urethane. The hydraulic jack can be placed under bottom 1.5 inch thick plate in each corner of parking frame.

Torque Screws

1. Torque parking frame alignment pin screw to 680 ft lb (1"-8 UNC, qty 1 to guide rail on each side of parking frame).

2. Torque vertical actuator swivel screws to 680 ft lb (1"-8 UNC, qty 4 each swivel, 16 total)

3. Torque center screw and perimeter screws on mounting block to 1400 ft lb (1 ¼-7 UNC, qty 1+12).

4. Torque wedge pusher screws (qty 6 ea) and side anti-rotate screws (qty 2 ea) to 680 ft lb (partial torque on 1 ¼-7 UNC). Gradually tighten screws while moving around pattern to ensure wedge ring is being driven in evenly. This will ensure a backlash free joint to the foundation plate.

5. Snug 1"-8 UNC wedge removal screws (qty 3).

Cleanup

1. At parking frame control enclosure, turn screw jack control selector switch to "Computer".

2. Install plastic plugs in tapped holes at old locations.

3. Clean floor, guide rail, and foundation plates at old location as required.

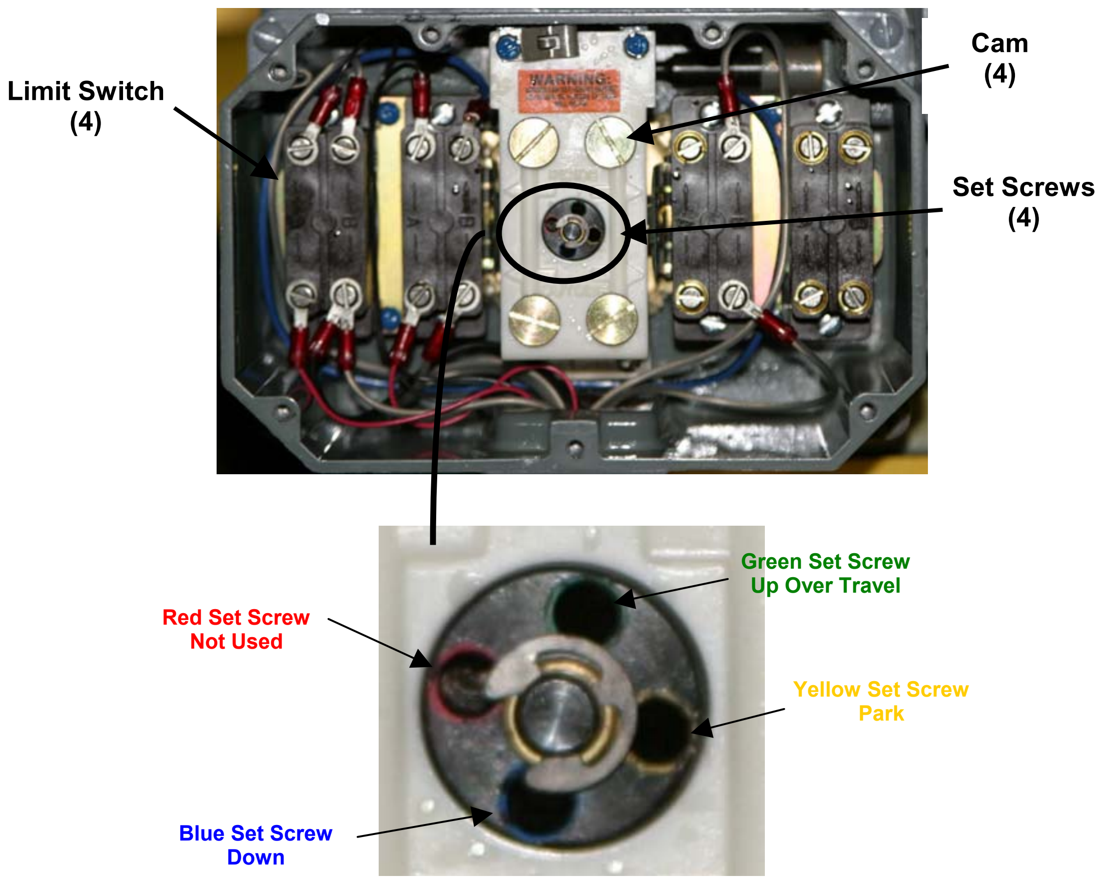
Limit Switch Adjustment Procedure

The instructions for adjusting the individual limit switches are on a label inside the limit switch cover on the parking frame.

Basically you need to loosen a set screw and turn a cam to engage the limit switch when at a desired location. The procedure is as follows:

NOTE: Reference Drawing # 100-078-275

1. Loosen the appropriate set screw on the limit switch using the allen wrench located in the cam switch box. Refer to the pictures and table below.



NAME	SET SCREW COLOR	LIMIT SWITCH	CAM
Park	Yellow	Inside Left	Top Left
Down Over Travel	Blue	Outside Left	Bottom Left
Up Over Travel	Green	Inside Right	Top Right
Not Used	Red		

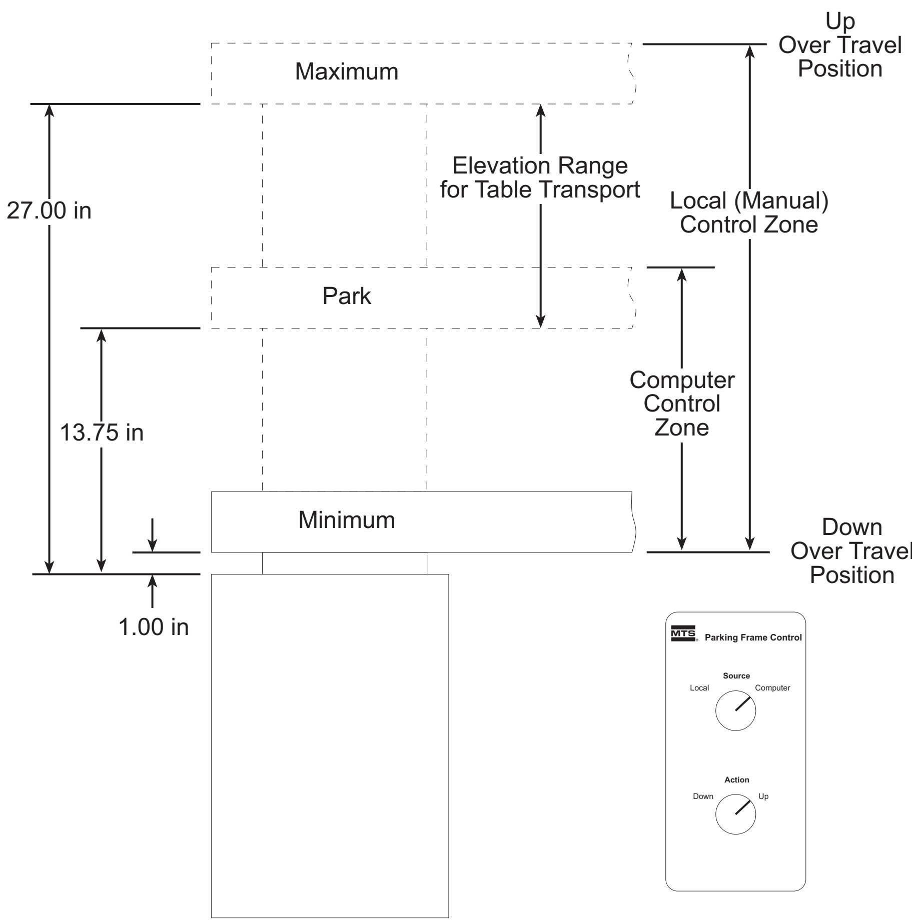
2. Move parking frame to desired location (down, park, or up). Refer to the drawing below for location dimensions:

***NOTE**: The down OT limit and the park limit are connected to the controller so you can verify those signals by looking at the opto 22 drawer (Din 6, opto #5 or DIN 7 opto #6). You will have to use an Ohm meter for the up OT limit.*

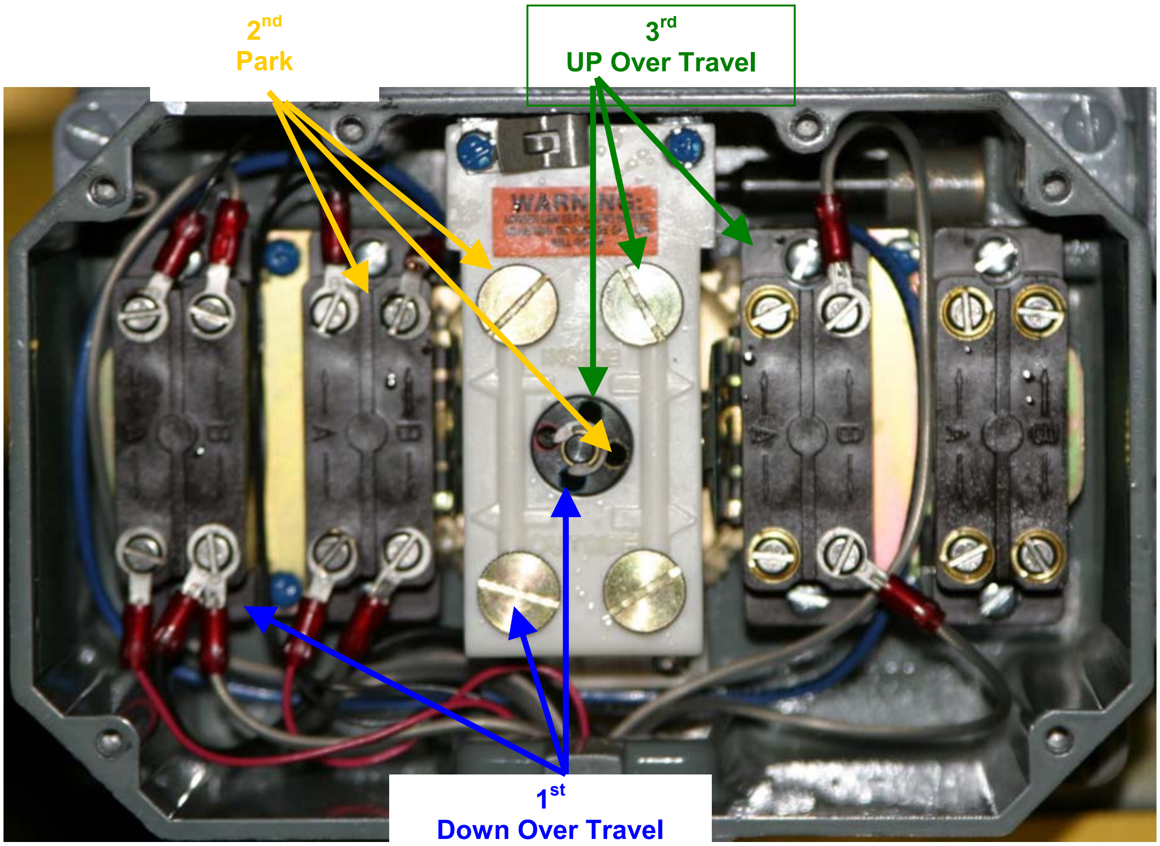
⚠ WARNING

When moving the parking frame, be careful not to go below the minimum or above the maximum positions.

Going beyond the minimum and maximum positions may stall and damage the gearbox.



3. Adjust appropriate cam to open appropriate limit switch. Do the **Down Over Travel** cam first, the **Park** cam second, and the **Up Over Travel** cam third.



4. Tighten appropriate set screw.
5. Verify limit by moving parking frame up and down (there is some hysteresis in the switch)
6. Re-adjust if necessary.

Table Hydraulic Shutdown Procedure

After the completion of a test, the following procedure should be completed to ensure safe shutdown of the test system.

Note *Do not use the EMERGENCY STOP (E-STOP) buttons during routine system shutdown. An emergency shutdown bypasses normal shutdown control sequences and, if used for routine shutdown, will place unnecessary mechanical strain on the system.*

System Shutdown

- If necessary, press the **Stop** button on the main panel to stop the test.
- Put all Adaptive Control functions into **Disable** mode.
- Ensure that the table is in the desired park position using the **Parking Frame Up/Down Arrows** on the main panel.
- De-energize **Main Hi**.
- Click on the **Main Lo** button.
- Click on the **Pilot On** button.

Emergency Shutdown Procedure

The following actions should be taken if an emergency arises during operation of the test system.

Note	*If the system electronics senses an exceeded limit or open interlock condition, a system shutdown will be activated automatically.*

- If an emergency situation occurs, activate an emergency shutdown by pressing one of the large red EMERGENCY STOP (or E-STOP) buttons.
- Correct the condition that caused the emergency shutdown.
- Execute the Hydraulic Turn On Procedure.

Using Adaptive Control

Adaptive control techniques are used to adapt to parameter changes in any system components that affect the control loop feedback of a system. The MTS seismic system can include four adaptive techniques, as described in Chapter 3 of this manual, "Understanding Control Principles":

- Amplitude/phase control (APC)
- Adaptive harmonic cancellation (AHC)
- Adaptive inverse control (AIC)
- Online iteration (OLI)

All adaptive controllers use three modes. The adaptive harmonic cancellers and adaptive inverse controller also have a training mode.

Disabled

Adaptive control is disabled.

Frozen

The system continues to use parameters developed during tracking, but the parameters are not updated.

In the case of online iteration, a new drive update file is calculated during each pass, but it is not used as the drive file for the next pass.

Tracking

The frequency response of the system is continuously measured and the applied inverse function is continuously modified to suit changing conditions in the system.

In the case of online iteration, a new drive update file is calculated during each pass, and this new file becomes the drive file for the next iteration.

Training (AIC and AHC only)

Training mode is used initially to build coefficients without affecting the system operation. A system model is built but the current signal being played out is not modified. These coefficients can then be saved in a settings file.

The choice of which adaptive controller to use is determined by two considerations: type of program waveform, and the degree of linearity of the entire system, including hydraulics, mechanics and test specimen.

System Type \ **Waveform Type**	Sine/Sweep	Other
Linear	Use Amplitude Phase Control (APC)	Use Adaptive Inverse Control (AIC)
Nonlinear	Use Amplitude Phase Control (APC) with Adaptive Harmonic Cancellation (AHC)	Use Adaptive Inverse Control (AIC) with Online Iteration (OLI)* * test must be able to tolerate iterations

Once you have determined which adaptive control technique(s) to use, refer to the appropriate section(s) below for operating procedures.

How to Use Amplitude/Phase Control (APC)

Amplitude/Phase Control (APC) is a control compensation technique that augments a fixed-gain controller to correct for closed-loop amplitude and phase irregularities in order to improve control fidelity. It measures control system dynamics directly and modifies the control compensation accordingly in realtime, making it possible to adapt to changing system dynamics.

APC is optimized to work with sinusoidal command waveforms (both fixed and swept frequency) and predominantly linear systems. If the command waveform is non-sinusoidal, use Adaptive Inverse Control (AIC) instead. If the system has significant nonlinearities, augment APC with Adaptive Harmonic Cancellation (AHC) to reduce harmonic distortion. APC and AHC complement each other: APC enhances the fundamental frequency component of the system response while AHC cancels the harmonics.

Operation

APC is very easy to use: just turn it on from the **Main Panel**, define a sine wave in the **Cyclic Function Generator** Panel or a sine sweep in the **Sine Sweep Function Generator** Panel, and press the **Run** button on the Main Panel.

Modifications

In most cases you will not need to adjust anything on APC Panel. However there are a few situations that may arise where you may want to make modifications:

- When operating at a frequency that is close a resonance such as the oil column resonance or a specimen resonance, APC may cause the response amplitude to oscillate . Usually this can be cured by reducing the convergence rate.
- When running sine sweeps at a fast sweep rate, you may find that APC is not able to adapt quickly enough to keep up. Try increasing the convergence rate. However, if you increase the convergence rate beyond unity, you risk APC instability and the large, potentially damaging motion that will result. You may have to reduce the sweep rate instead.
- For safety purposes you may want to reduce the Max Authority value to reduce the danger of damage due to large amplitude motion should APC's adaption process become.
- If you observe that the response amplitude falls short of the command amplitude, it may be because the amplitude correction

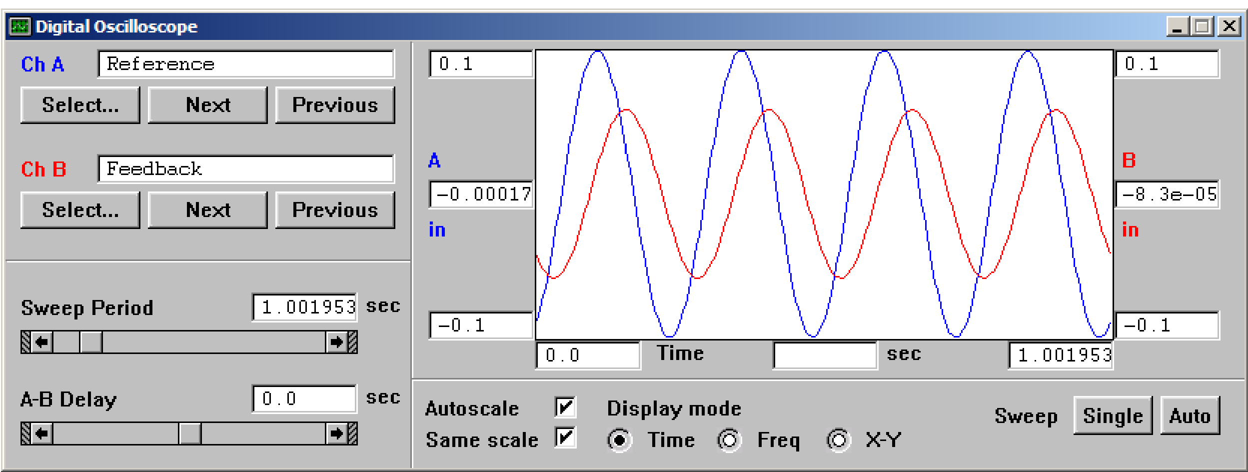
that APC needs to apply is beyond the maximum authority limit. You can verify that this is the case because the Amplitude Correction display value will be nearly equal to the Max Authority value. Increase the Max Authority in small increments, until the response amplitude matches the command and the Amplitude Correction falls below the Max Authority. If the response amplitude does not increase when Max Authority is increased, you may be at a physical limit of the system, in which case there is nothing you can do except reduce the command amplitude or frequency.

You may also want to access the APC Panel to verify that adaption is occurring by observing the changing correction values in the Amplitude and Phase Correction displays, or by noting the green color of the tracking indicator next to the Convergence Rate slider bar.

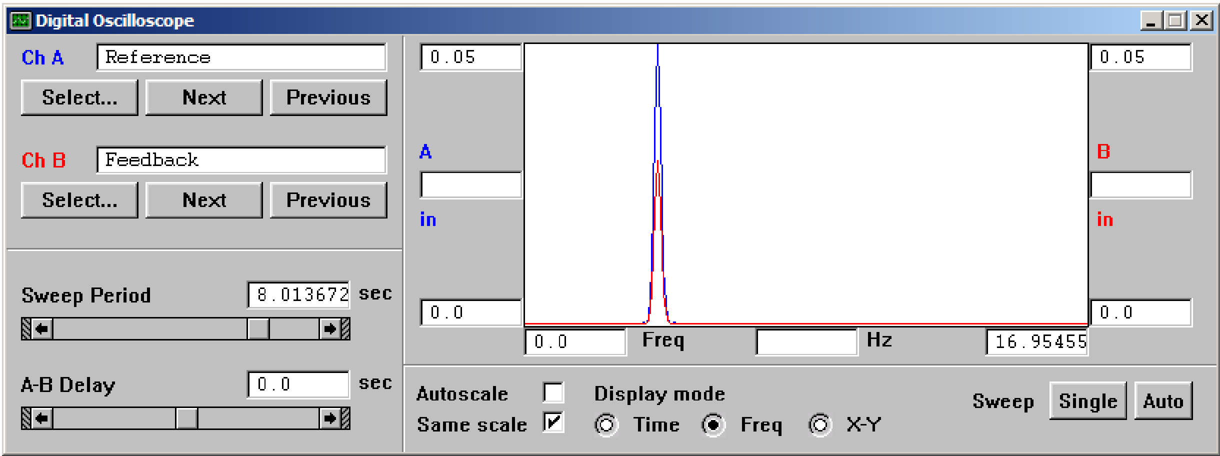
Viewing the Results

You can use the **Digital Oscilloscope** to monitor command and response waveforms in either the time domain or the frequency domain. In all examples shown below, command is shown on Channel A (blue) and response on Channel B (red).

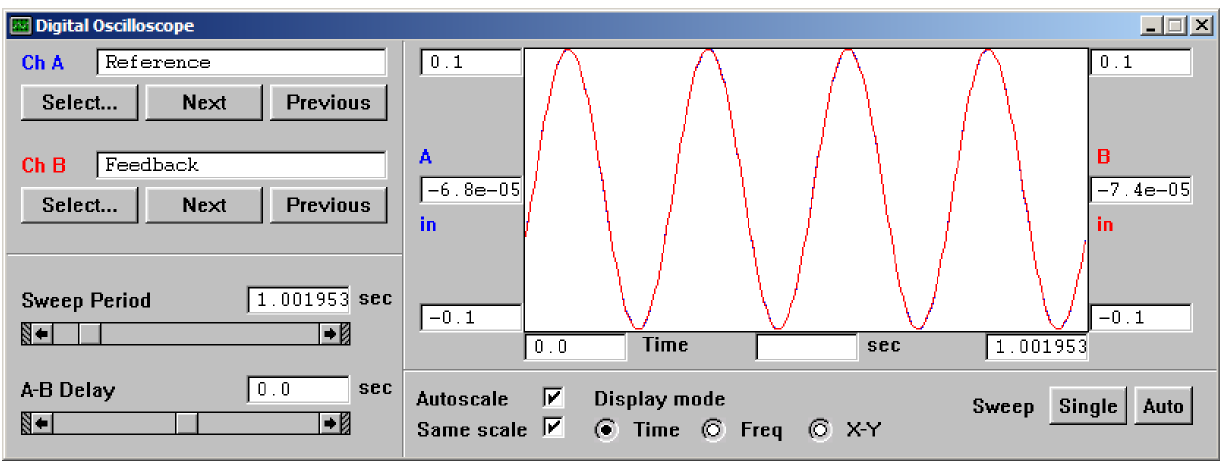
Below is an example showing command and response time domain signals without APC:



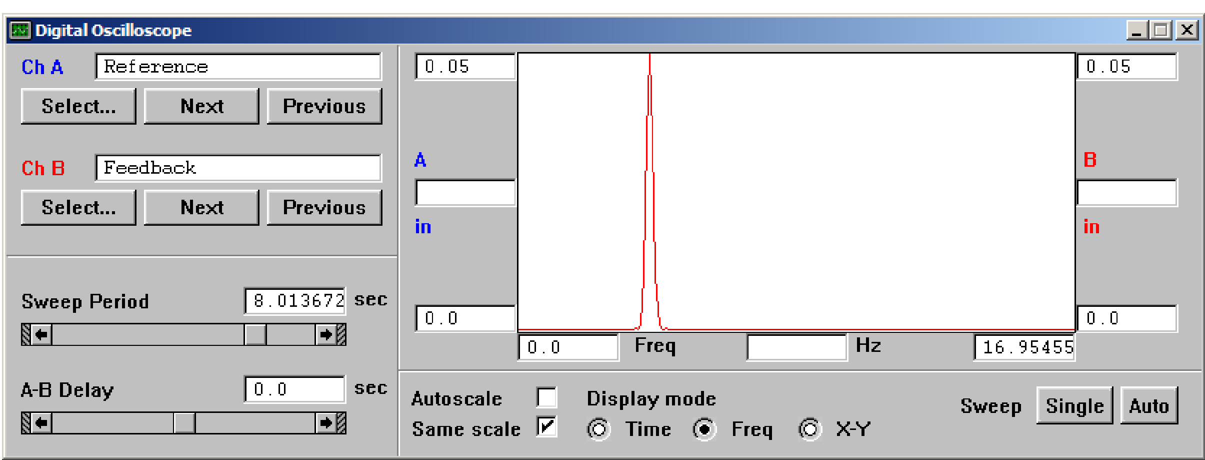
In the frequency domain, the response amplitude obviously falls short of the command amplitude:



With APC, command and response time domain signals are almost perfectly overlaid:



In the frequency domain, the response amplitude matches the command amplitude:



How to Use Adaptive Harmonic Cancellers (AHC)

Adaptive Harmonic Cancellation (AHC) greatly reduces harmonic distortion of the response of a control system driven by a sinusoidal command. It measures the harmonic distortion directly and adapts in realtime the cancelling waveform that it applies to the control system input.

AHC is optimized to work with sinusoidal command waveforms (both fixed and swept frequency). To improve the fidelity of the system's response to a sine command, AHC can be augmented with Amplitude/Phase Control (APC). APC and AHC complement each other: APC enhances the fundamental frequency component of the system response while AHC cancels the harmonics.

Training the Model

Perform the following procedure for every active control channel:

Step 1: Set up the random function generator. The 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:

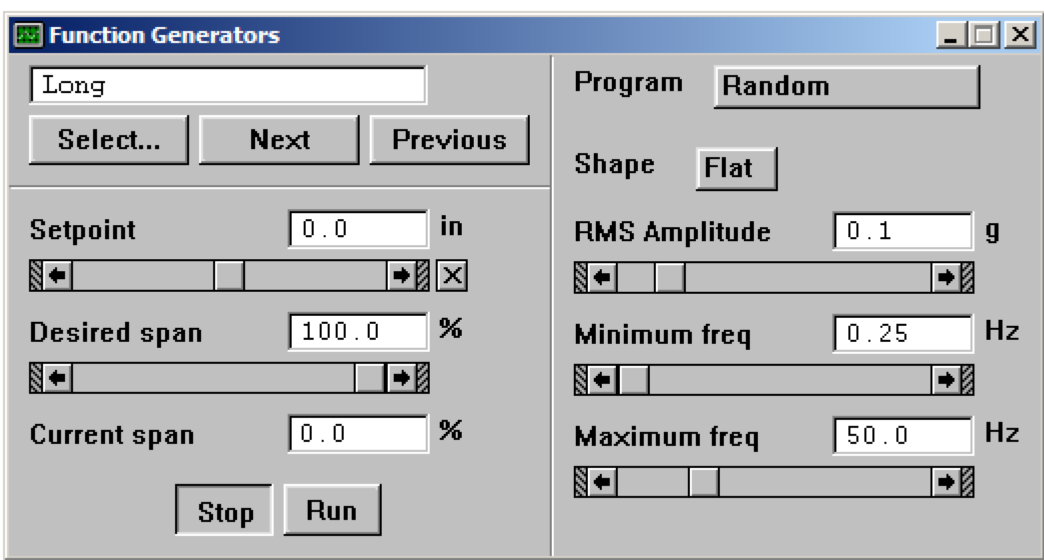
Maximum frequency: This is the cutoff frequency of the bandpass filter. Set this according to the highest frequency expected in your test waveform. Due to internal technical considerations, this maximum frequency must not exceed 64 Hz. Also enter this maximum frequency into the Maximum Frequency edit box in the AHC Panel. This tells AHC not to cancel harmonics that exceed the frequency up to which its model has been trained.

Minimum frequency: This is the cut-in frequency of the bandpass filter. Set this according to the lowest frequency expected in your command 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.

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 will result in an inaccurate estimates of the plant model. 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 somewhat 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 1% of the maximum frequency when "1/F" and "1/F^2" shapes are selected.

An example random function generator setup is as follows:

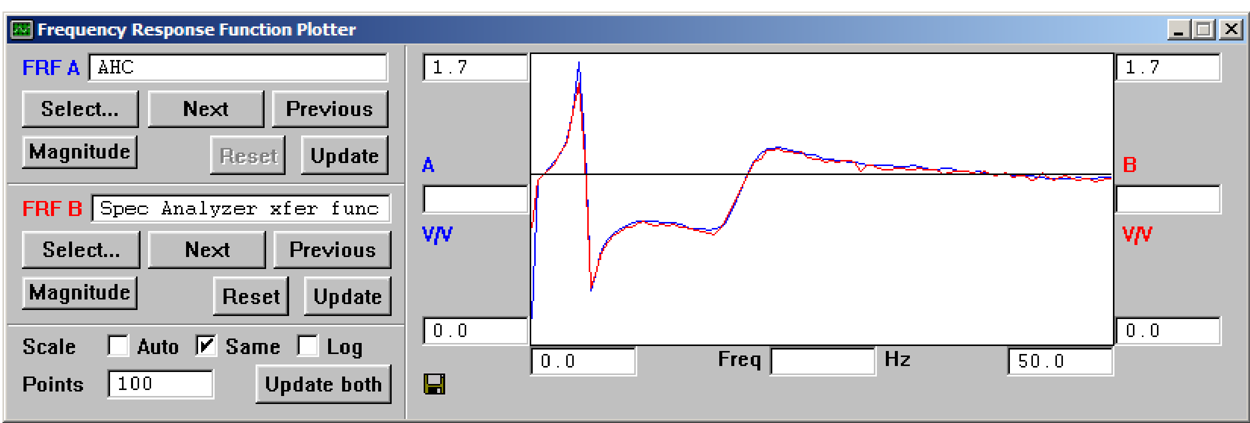


Step 2: Turn on AHC in Training mode from the Main Panel. In Training mode, AHC is on but is not canceling. Instead, it passively monitors command and feedback to the plant and updates its model accordingly.

Step 3: Run the random function generator. First, make sure that the function generators of all other channels are in a stopped state. Then start the function generator by pressing the Run button.

Step 4: Adapt the coefficients. When motion has begun, move the Model 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 model coefficient display of the AHC Panel, and graphically in the FRF and IRF Plotters. Another indication of adaptation is the green color of the tracking indicator next to the Model 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 function estimated by AHC with that estimated independently by the Spectrum Analyzer. In the example, Channel A (blue) of the FRF Plotter shown below shows the model's transfer function identified by AHC; 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 AHC transfer function are effects of filters internal to AHC that the Spectrum Analyzer cannot see.



When the coefficients have stopped changing alot, 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. Finally, after the convergence rate has been reduced to zero, stop the function generator by pressing the Stop button.

Training is now complete. At this point is a good idea to save AHC setup and transfer function coefficient values to a settings file using the Main Panel's File, **Save Settings** menu item.

Canceling the Harmonics

Perform the following procedure for every active control channel:

Step 1: Set up the sine or sine sweep function generator.

Step 2: Turn on AHC in Tracking mode from the Main Panel. At this point you may also want to turn on Amplitude/Phase Control (APC) to improve the fidelity of response to the sine command.

Step 3: Run the sine or sine sweep function generator. First, make sure that the function generators of all other channels are in a stopped state. Then start the function generator by pressing the Run button.

Step 4: Cancel selected harmonics. After motion has begun, observe the response using the Digital Oscilloscope. It is convenient to view the response in Frequency Display Mode so that individual harmonics are easily discernable. Noting which harmonics have significant amplitude, designate them for cancellation by pressing the corresponding buttons in the Harmonics grid selector in the AHC Panel. Then move the Canceller Convergence Rate slider bar away from zero. In the Digital Oscilloscope, selected harmonics will begin to shrink in amplitude. The authority displayed in the AHC Panel will increase as the amplitudes of the cancelling signals that AHC adds to the command are increased. Another indication of adaptation is the green color of the tracking indicator next to the Canceller Convergence Rate slider bar.

If the authority reaches the maximum authority limit, it is either because the maximum authority is too low, or AHC is unstable at that harmonic. To determine which is the case, increase the Max Authority in the AHC Panel by small increments while observing the response harmonics in Digital Oscilloscope (in Frequency Display Mode). If the amplitude of a harmonic keeps increasing with increasing authority, then AHC is unstable at that harmonic. Almost always the cause of this behavior is an inadequately trained plant model. You may need to go back and retrain or refine it.

Reducing the maximum authority to the minimum possible will reduce the danger of damage due to large amplitude motion should AHC's adaption process become unstable for whatever reason.

When running sine sweeps at a fast sweep rate, you may find that AHC is not able to adapt quickly enough to keep up. Try increasing the convergence rate. However, if you increase the convergence rate beyond unity, you risk AHC instability and the large, potentially damaging motion that will result. You may have to reduce the sweep rate instead.

Canceling Cross-Coupling Disturbance

AHC can be used to cancel the cross-coupling disturbance that sometimes occurs in a multichannel control system when motion on one channel couples into another. Using the term "primary" to refer to the primary motion channel and "secondary" to refer to the channel disturbed by the primary channel, apply the following procedure to the secondary channel:

Step 1: Train AHC as usual.

Step 2: Set up the phased function generator. The phased function generator synchronizes itself both frequency- and phase-wise with another channel's function generator (called the "master" function generator). In this case, designate the primary motion channel's sine generator as the master. Next, specify a very small amplitude, small enough for the resultant motion to not be noticeable. Even though no motion is desired on the secondary channel, you must drive it with sine command becauses AHC uses it to drive its internal harmonic generators. The command amplitude does not have to be large, but it does have to be nonzero.

Step 2: Turn on AHC in Tracking mode from the Main Panel.

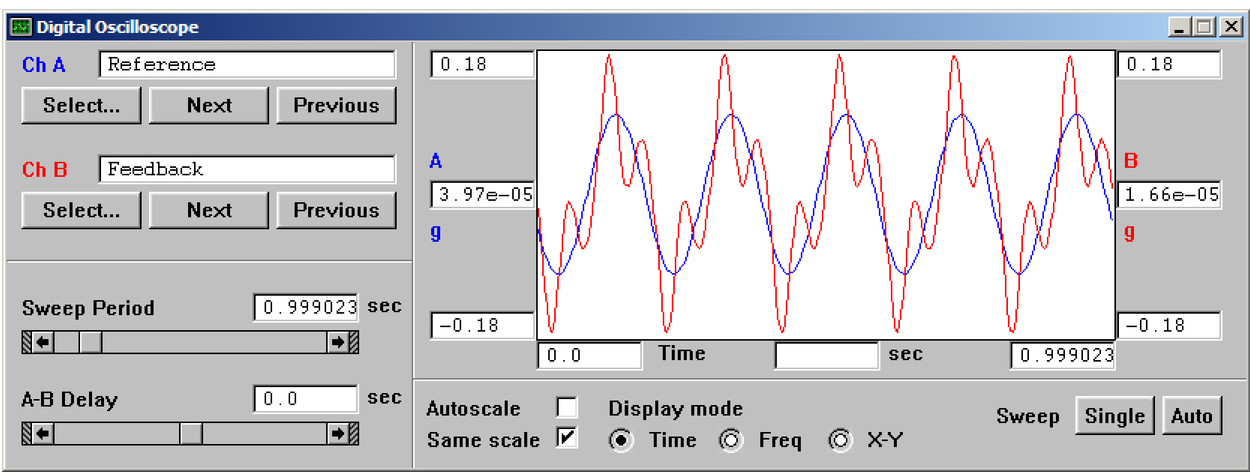
Step 3: Run the sine or sine sweep function generator. Start the primary function generator by pressing the Run button. The secondary function generator will start as well because it is linked to the primary function generator.

Step 4: **Cancel selected harmonics.** When you observe the secondary channel's response in the Digital Oscilloscope (in Frequency Display Mode), there will probably be a sizeable component of disturbance at the fundamental frequency, i.e., the primary function generator's sine frequency. Cancel this "first harmonic" by selecting the "1" button of the Harmonics grid selector in the AHC Panel. Note that the first harmonic button is used only to cancel cross-coupled disturbance at the fundamental frequency on secondary channels. It is not used for regular cancellation on primary channels.

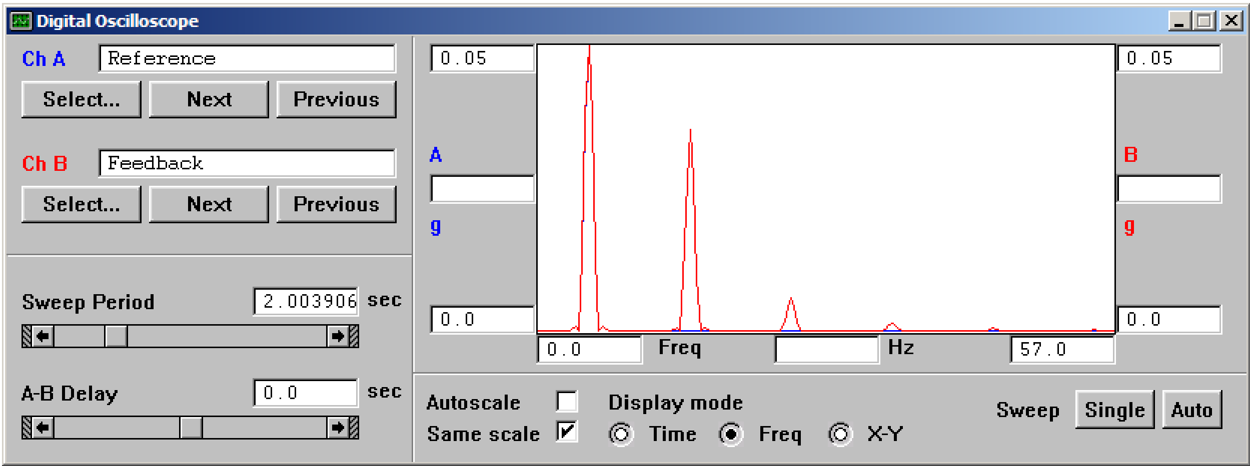
Viewing the Results

You can use the **Digital Oscilloscope** to monitor command and response waveforms in either the time domain or the frequency domain. In all examples shown below, command is shown on Channel A (blue) and response on Channel B (red). APC is enabled in all of these examples.

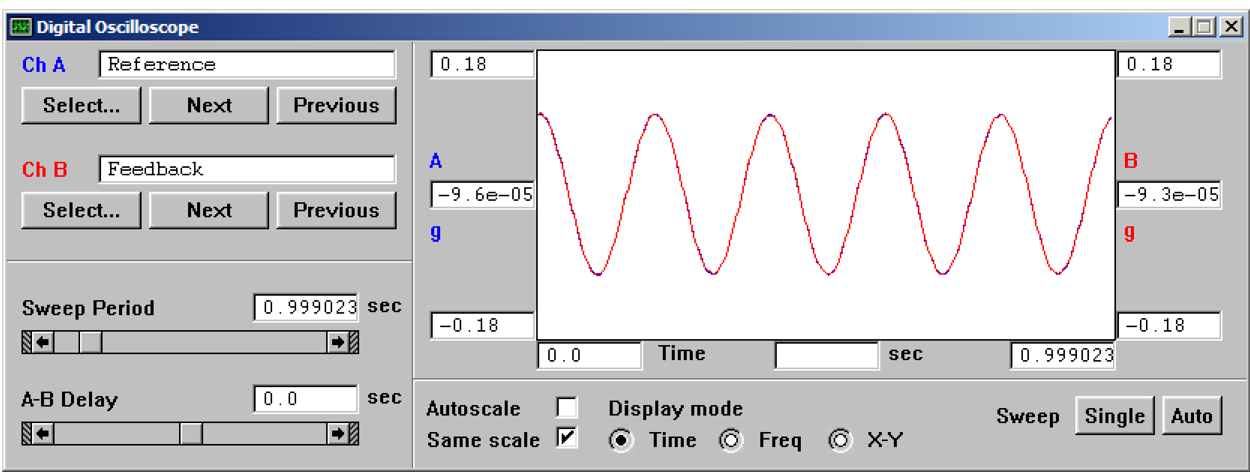
Below is an example showing command and response time domain signals without AHC:



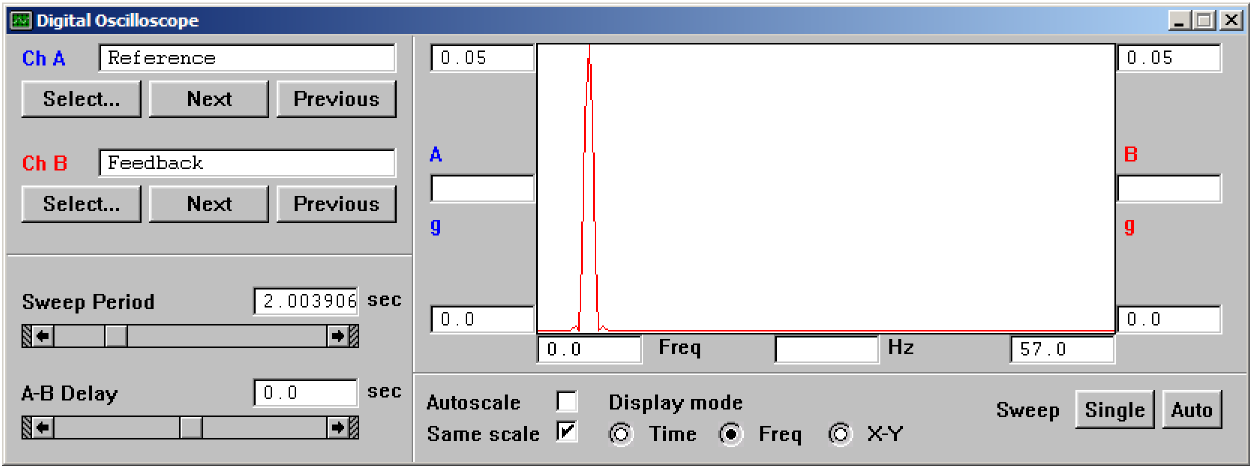
In the frequency domain, harmonics are clearly visible in the response:



With AHC, the harmonics are gone and, because of APC, command and response time domain signals are almost perfectly overlaid:



In the frequency domain, the harmonics are gone and the response amplitude at the fundamental frequency matches the command amplitude:



How to Use Adaptive Inverse Control (AIC)

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).

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. Only the Long and Lat channels will be used.

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

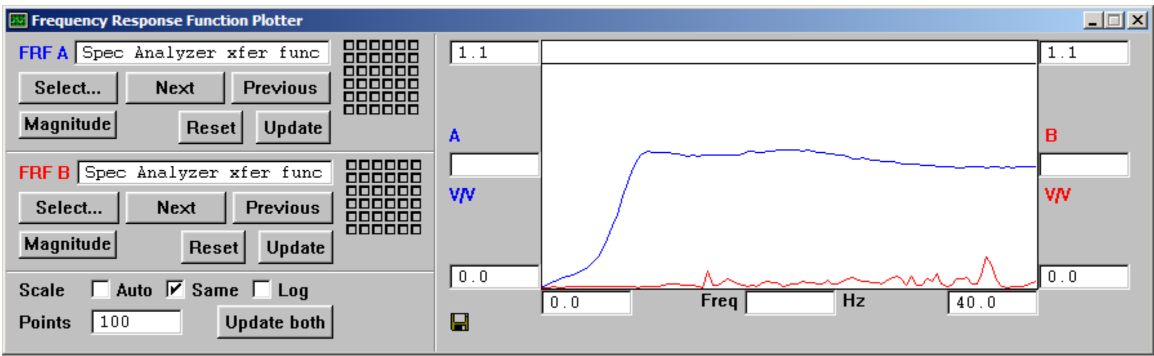
- Main Panel
- Function Generator Panel
- Spectrum Analyzer Panel
- Frequency Response Function (IRF) Plotter
- Impulse Response Function (IRF) Plotter
- Digital Oscilloscope

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 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".

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 transfer function matrix element by unchecking its Active checkbox.

In the example, Channel A (blue) shows the Long->Lat transfer function magnitude; Channel B (red) shows the Long->Vert transfer function magnitude. The cross-coupling between Long and Lat is obviously significant and should not be pruned out. The cross-coupling between Long and Vert is small and can be pruned out of the transfer function matrix.



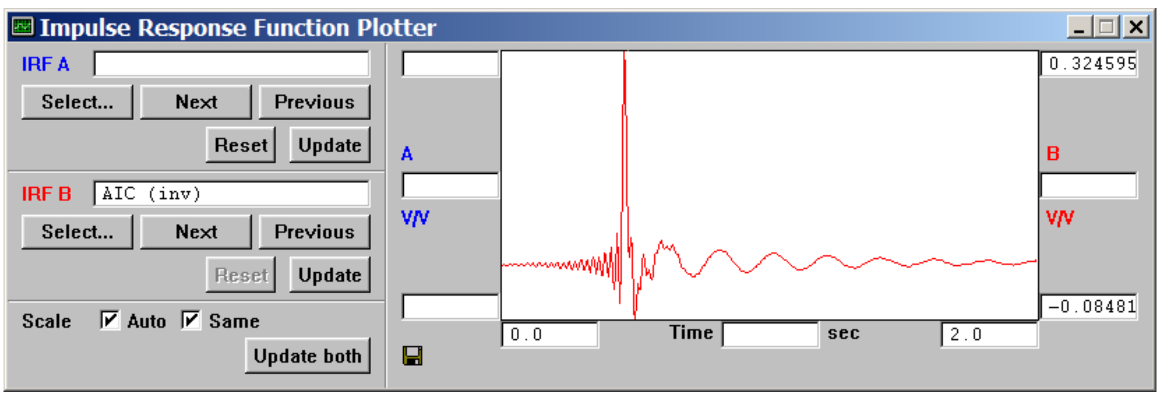
When pruning the forward transfer function matrix, you must maintain matrix symmetry. If (for example) the Long->Lat element is active, then the transpose element Lat->Long must also be active. Another rule is that if any element of a matrix row is active, the diagonal element in that row must also be active. Note that this is true only of the forward transfer function matrix; the inverse transfer function matrix is somewhat less restrictive.

The inverse transfer function matrix is pruned identically to the forward transfer function matrix, except that the rows corresponding to channels that you do not intend to excite can be deactivated. In the above example, if only Long is to be excited with a command waveform and Lat is to be kept at zero, only the Long row of inverse elements needs to be active. This is convenient because only the rows corresponding to nonzero command channels have to be trained.

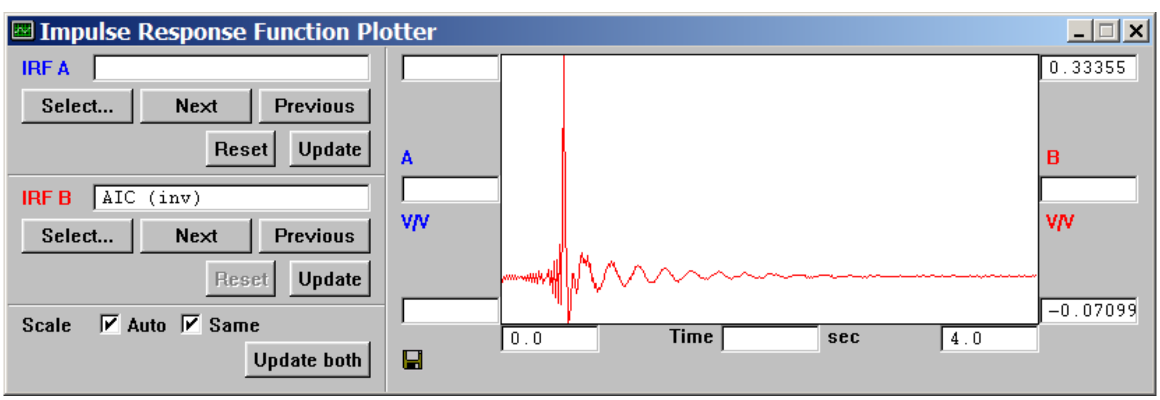
Determining the Impulse Response Length and Anticipation Delay

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. 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. There is no simple rule for determining the impulse response length. So finding optimum values for these quantities is best done by trial and error, as follows:

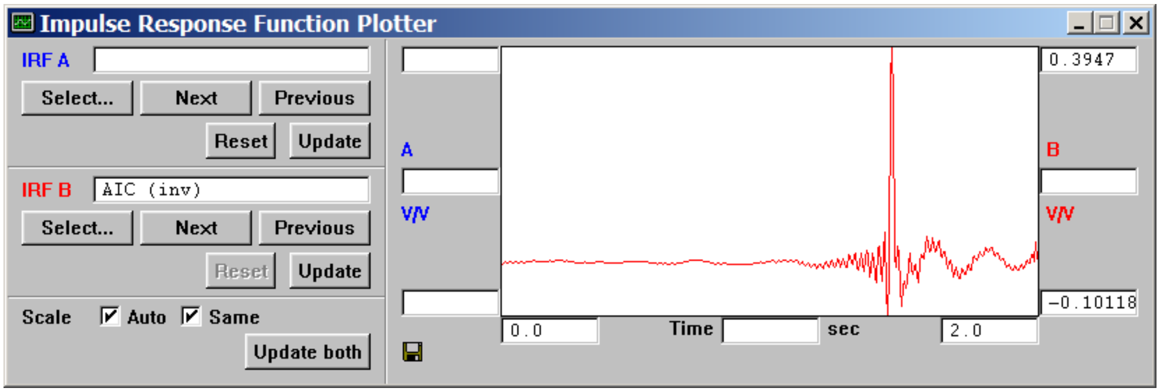
First, choose a long impulse response length, and set the anticipation delay to half of this length. Then train the forward and inverse transfer functions using the Training procedure described in later sections. Using the Impulse Response Function (IRF) Plotter, verify that the inverse impulse responses are neither too short nor too long. 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, as shown here:



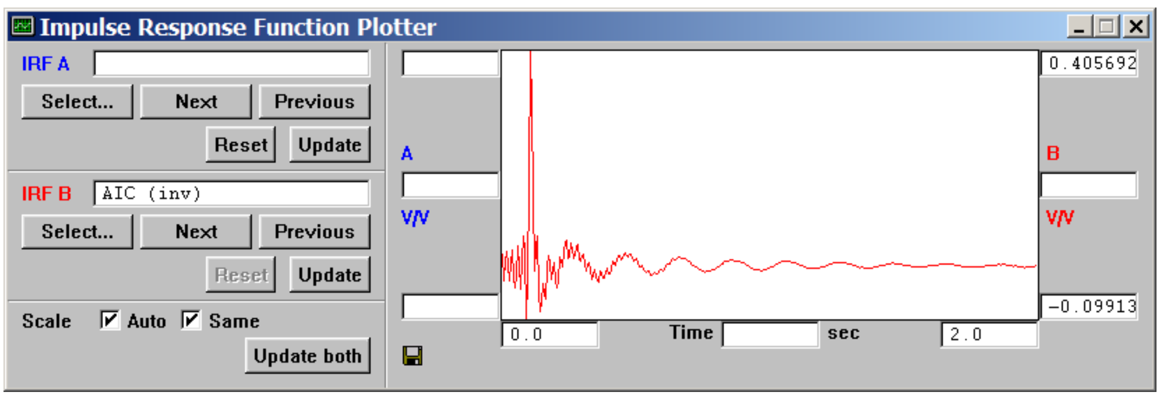
This impulse response has too many zeros on the tail end, so the impulse response length should be reduced:



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



(The anticipation delay determines the approximate location of the main pulse within the impulse response interval.) This impulse response has a truncated front end, so the anticipation delay should be increased to move the impulse to the right:



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

- To save time, train only a single channel.
- To save time, examine only the inverse impulse responses and ignore the forward impulse responses. The inverses are typically much longer than the forwards, so an impulse response length that satisfies the inverses automatically satifies the forwards.
- 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.** As discussed in a previous 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:

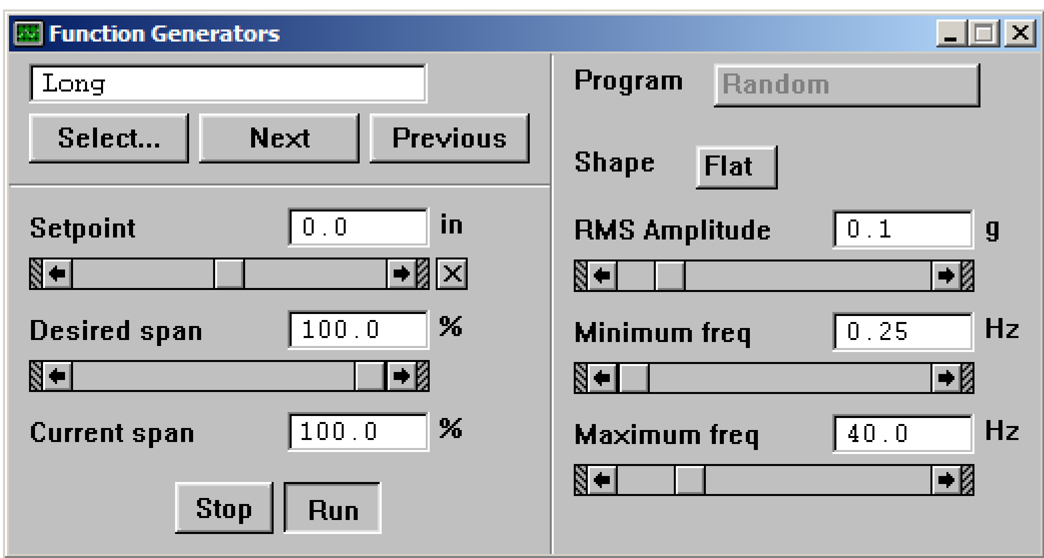
Maximum frequency: This is the cutoff frequency of the bandpass filter. Set this according to the highest frequency expected in your test waveform. Due to internal technical considerations, this maximum frequency must not exceed 64 Hz. Also enter this maximum frequency into the Maximum Frequency edit box 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 edit box 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 will result in inaccurate estimates of the transfer function. 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 somewhat 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 1% of the maximum frequency when “1/F” and “1/F^2” shapes are selected.

In the example, both Long and Lat random function generators are set up as follows:



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.

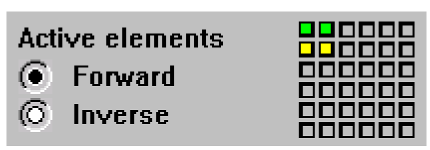
Step 4: Set the noise level. After waiting at least two impulse response intervals after turning on AIC, press the Noise Level Set button. This causes AIC to measure its feedback noise level to determine the response threshold below which it will inhibit adaptation. This prevents AIC from adapting to 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 observer bandwidth.
- Any controller gain setting.
- Feedback conditioner filter bandwidth.

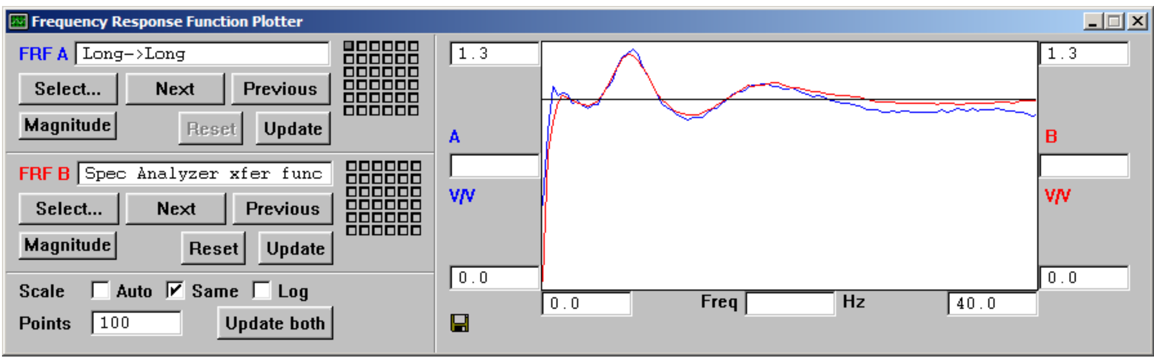
When setting the noise level, make sure that AIC is on with the convergence rates set to zero and that the system is at rest for a period of time at least as long as twice the impulse response length. If you make the common mistake of setting the noise level when the system is in motion, set it to back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

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. In the example, all elements in the Long row are unfrozen and and all elements in the Lat row are frozen, resulting in an Activation Status grid display that looks like this:



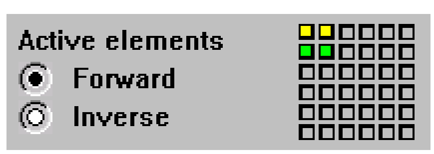
Next, make sure that the function generators of all other rows are in a stopped state. Then start the function generator by pressing the Run button. After motion has begun, move the Forward Convergence Rate slider bar away from zero. The coefficients of elements in the training row will begin to change. 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. In the 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.



When the coefficients have stopped changing alot, 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. Finally, after the convergence rate has been reduced to zero, stop the function generator by pressing the Stop button.

Step 6: **Train subsequent active rows of transfer function elements.** Repeat the previous step for all other active rows. In the example, all elements in the Long row are frozen and and all elements in the Lat row are unfrozen, resulting in an Activation Status grid display that looks like this:



During the training sequence 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.

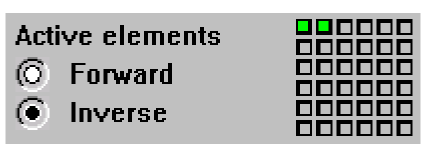
Training the Inverse Transfer Functions

Training the inverse transfer functions can be done with hydraulics off because AIC uses only internal forward model feedbacks rather than real 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.** As discussed in a previous section.

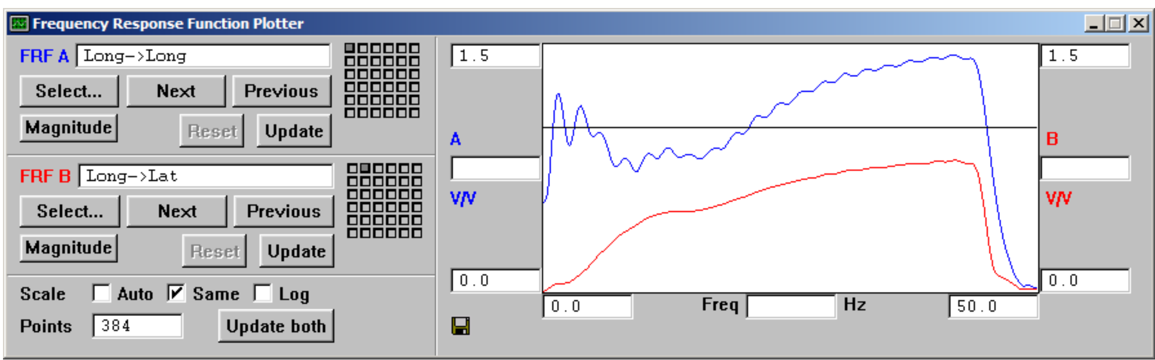
Step 3: **Train all active transfer function elements.** Unlike the forward transfer function matrix, which can be trained row by row, all active elements of the inverse transfer function matrix should be trained simultaneously. (Although it is possible to train column by column, there is no advantage in doing so.) First, unfreeze all elements in the inverse transfer function matrix. In the example, the Activation Status grid display then looks 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 inverse transfer functions using the FRF Plotter. In the example, Channel A (blue) of the FRF Plotter shown below shows the Long->Long inverse and Channel B (red) shows Long->Lat inverse. These are typical of on- and off-diagonal inverses.



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); anything greater than 5 or so is considered "large". 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. For example, if Long has relatively coarse G units and the Pitch has relatively fine degrees/sec/sec units, the Long->Pitch inverse can have large magnitude and still be okay. Keep units disparity in mind when interpreting off-diagonal inverses.

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 stopped changing a lot, polish them as described previously.

When all active elements of the inverse transfer function matrix have been trained, you can either further refine the inverse transfer function matrix or proceed to running your test.

Refining the Inverse Transfer Functions

Inverse training as described above will provide a reasonably good inverse for control purposes, but the inverse can often be improved by switching to Tracking mode.

However, keep in mind that in Tracking mode AIC is actively controlling the plant, and therefore the potential for instability exists. The motion that can result from an inadequately or improperly trained inverse can instantly destroy your specimen and damage your test machine. So before you switch from Training to Tracking mode, take time to examine all active inverse transfer functions using the **FRF Plotter** to verify that they make sense. Do not enable Tracking mode otherwise.

To refine the coefficients, simply repeat the steps outlined in the previous section in Tracking mode instead of Training mode. Use a small inverse convergence rate to obtain a more accurate inverse. If you wish, you can also refine the forward transfer functions at the same time using a small forward convergence rate.

Before pressing the stop button, switch to Frozen mode or manually set both convergence rates to zero. That way the transfer functions won't change as signal amplitudes decrease to zero.

Training is now complete. 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

When you run a test, you will switch AIC to Frozen or Tracking mode. 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. This means that when you press the **Run** button on the Main Panel to run your test, you won't see any motion for 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.

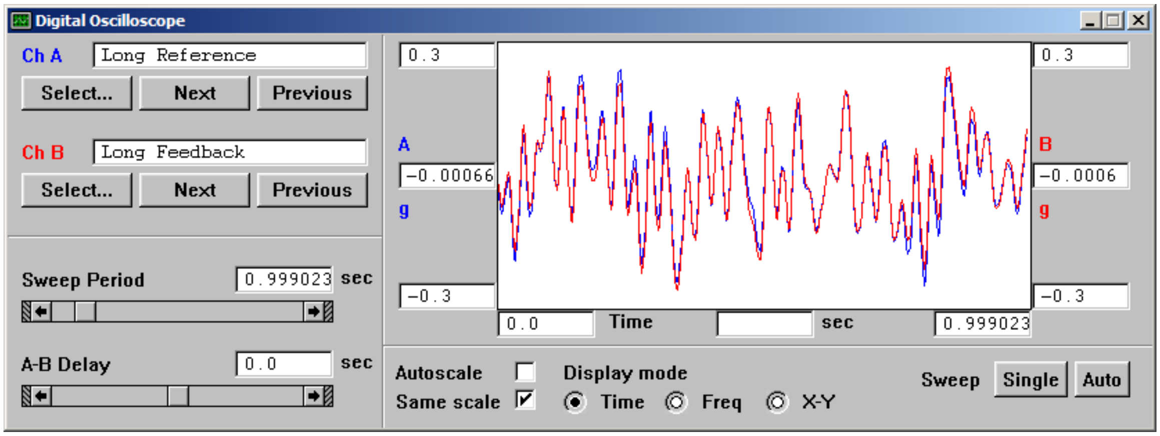
The decision of whether to run in Frozen or Tracking mode depends on the duration of the test and whether or not you expect plant dynamics to change significantly during the test. If you expect the dynamics to change significantly *and* the test duration is long enough for AIC to adapt to those changes, 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 hasS20 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.

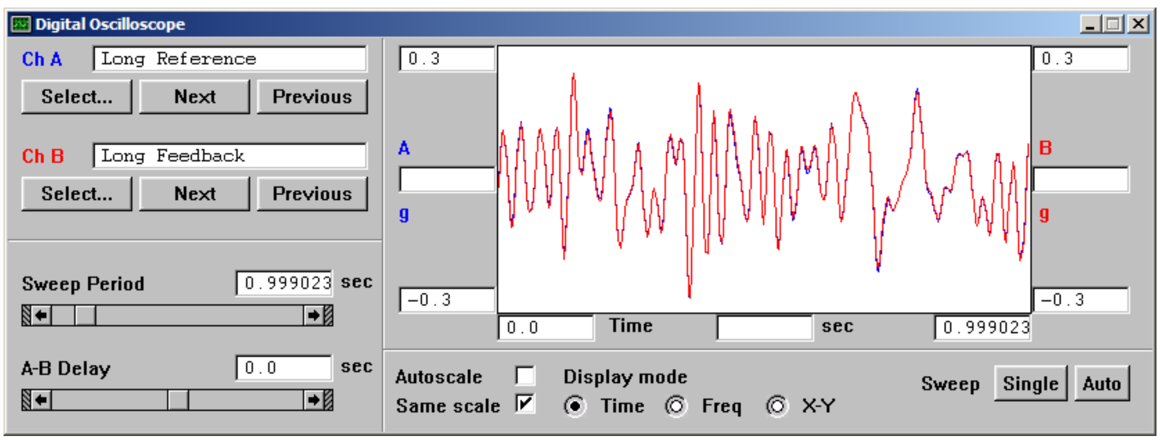
Viewing the Results

You can use the **Digital Oscilloscope** to monitor command and response time waveforms, or the **Spectrum Analyzer** and the **FRF Plotter** to observe transfer functions and power spectral densities (PSD's).

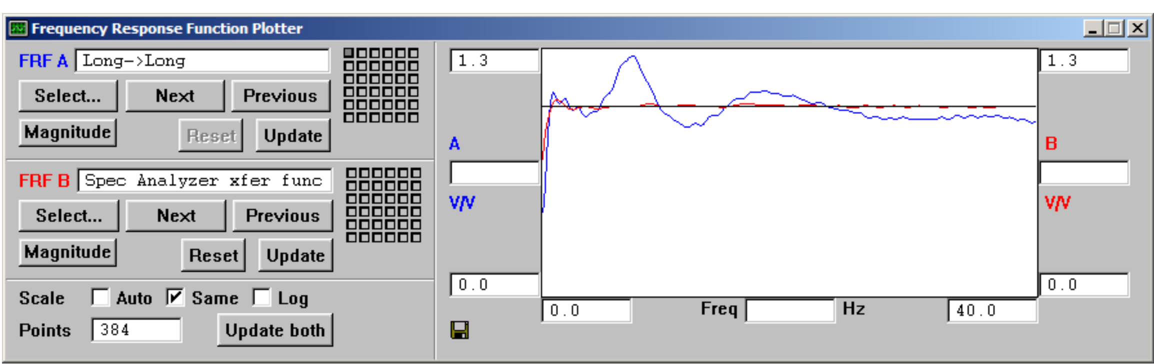
Below is an example showing Long command and response without AIC:



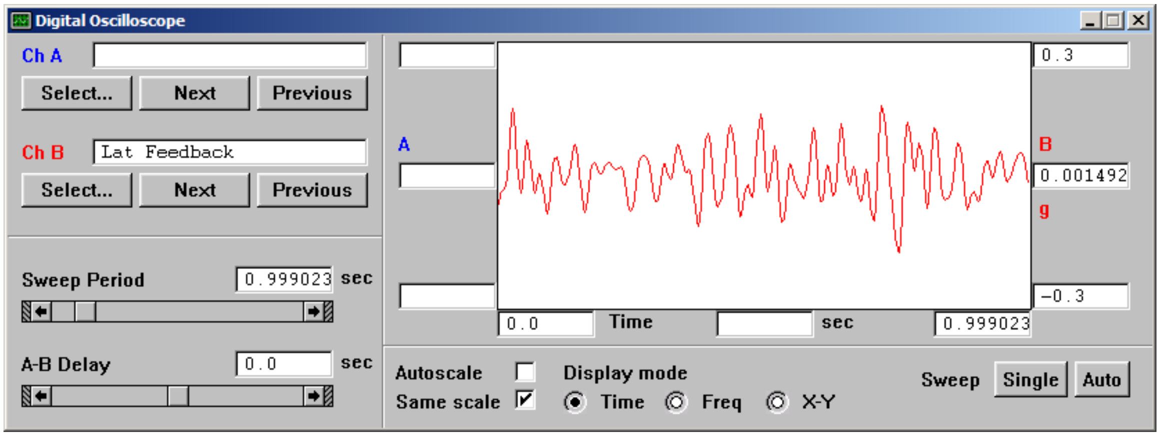
With AIC, Long command and response are almost perfectly overlaid:



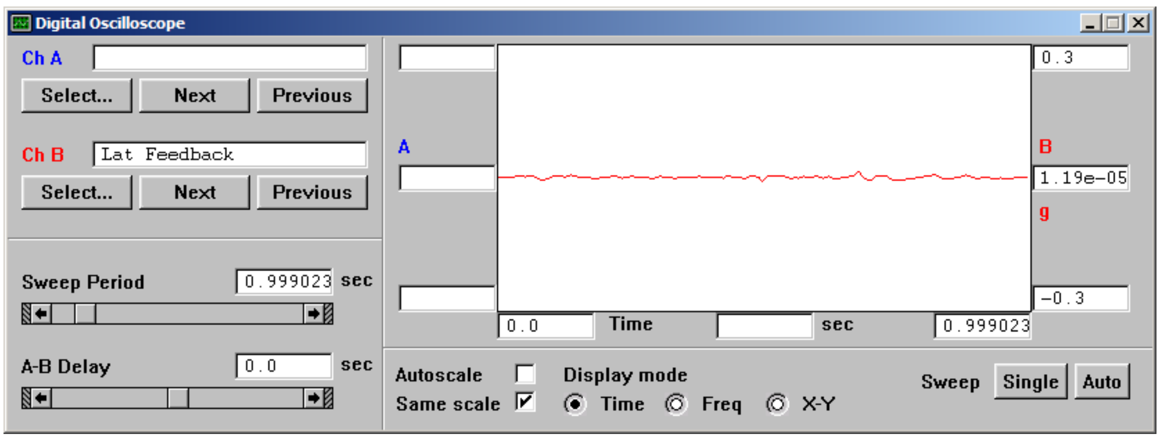
Long->Long frequency response with AIC (Channel B (red)) shows a substantial improvement over that without AIC (Channel A (blue)) andS20 is almost perfectly unity at most frequencies:



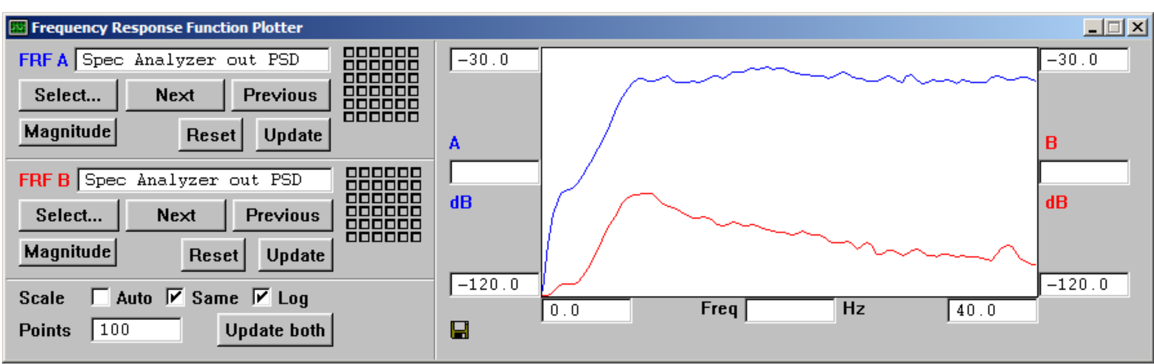
Below shows the cross-coupling on Lat due to Long without AIC:



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



The PSD of cross-couS20pling on Lat due to Long (Channel B (red)) shows a 40 to 80 dB reduction over that without AIC (Channel A (blue)):



How to Use Online Iteration

Online Iteration (OLI) is a control technique that repeatedly modifies the command input to a control system on an individual sample-by-sample basis until the control system response is almost a perfect replica of the original desired command.

OLI is optimized to work with non-sinusoidal command waveforms and significantly nonlinear systems. If the command waveform is a pure sine wave, Adaptive Harmonic Cancellation (AHC) works better and is easier to use. If the system does not have significant nonlinearities, use Adaptive Inverse Control (AIC) instead.

The focus of OLI is two time history files, the "desired" file and the "drive" file. The desired file is an unchanging file that contains the time history that you want to reproduce on the test system. The drive file is a time history file that is modified every time it is played out in such a way as to cause the system response to eventually match the desired time history. The process of repeatedly playing out the desired and drive files while updating the drive file is called "iteration".

OLI requires knowledge of the inverse transfer function of the plant in order to compute a drive correction. This inverse transfer function is provided by the Adaptive Inverse Controller (AIC), appropriately rewired to serve in this role, and is determined by a training process prior to running OLI; refer to the sub-section "How To Use AIC" for details.

Operation

Step 1: Train the Adaptive Inverse Controller (AIC). OLI uses AIC's inverse transfer functions, which must be identified during a training process. Consult the section on training tranfer functions in the document "How To Use AIC".

Step 2: Prepare the desired time history file. MTS's time history files have a proprietary binary format for which MTS provides two file translators. One translator translates a text file that you create using a text editor or a spreadsheet program. The text file must have the sample period on the first line, followed by a column for each data channel. For example:

```
0.00390625
0.0          0.0          0.0
-0.00021  0.00012      0.000867
-0.00033  0.000209     0.000957
-0.00036  0.000359     0.000987
```

-0.00042	0.000389	0.000389
-0.00036	0.000359	0.00012
(etc.)		

After creating this text file, invoke the translator from the Main Panel File, Translate, Text to Binary menu item. You will be prompted for the name of the text file and a name for the binary file. Use the same name as the text file for the binary file but with a different extension. You can use any file extension you wish for desired time history files, but we recommend that you use ".des" for convention.

Another translator is provided for use within MathWorks' Matlab computation environment and translates Matlab arrays directly into binary time history files. The translator is a Matlab script "savebin.m" that you can run from Matlab's command window; type "help savebin" after the command prompt to see how to use it.

When preparing a desired file, there are several restrictions that apply:

- The data in the file must have a sample period of 1/256 second.
- The number of channels in the file must be equal to the number of control channels.
- The time histories must begin and end at zero. For best results, you should also append an additional 1-2 seconds of zero samples at both ends.
- The signal content in the time histories must not exceed 64 Hz.

Step 3: Turn on OLI in Tracking mode from the Main Panel. AIC will be automatically turned on in Frozen mode if you have not already done so.

Step 4: Enter the desired master span and hit the Run button on the Main Panel. You can iterate at 100% amplitude, or you can iterate at a reduced level such as 10-20% to minimize damage to your specimen, then after completing the iteration process, run the test at 100% span. Mathematically, linear scaling is not a valid operation in nonlinear systems, but nonetheless this technique often works quite well.

Step 5: **Select the desired time history file.** Using the Desired File Open button, select the desired time history file.

Step 6: **Create the first drive time history file.** Using the Drive File New button, begin a new series of drive files by entering the root name of the drive file series and press OK. We recommend that you use the default root name, which is the same as the root name of the desired file. For example, if the desired file name is "myfile.des", the default root name is "myfile", and the sequence of drive files created during iteration will be "myfile.d00", "myfile.d01", "myfile.d02", etc. The first drive file in the series "myfile.d00" will be filled with zeros.

Alternatively, you can create your own initial drive file that contains a scaled down version of the desired rather than just zeros. This may reduce the number of iterations. In this case, use the Drive File Open button instead of the Drive File New button.

Step 7: **Enter an iteration gain.** The iteration gain determines how many iterations it takes to converge to the final solution. The ideal case is an iteration gain of 1.0, in which case convergence occurs in a single iteration. However, an iteration gain this high only works with a perfectly linear system; in a nonlinear system iterations would diverge. In general, the more nonlinear a system is, the lower the iteration gain must be for convergence, and therefore the greater the number of iterations that must be performed.

Only by experience will you know what iteration gain is appropriate for your testing situation. If you don't know what iteration gain to use, start with 0.5. Watch the trend of the response errors as iterations progress. If response errors monotonically decrease, it is probably okay to increase the iteration gain. If response errors oscillate up and down from iteration to iteration, you should decrease the iteration gain.

If you find that you are using an iteration gain of nearly one, your system is probably linear enough that you don't have to use OLI. If this is the case, just use AIC.

If you use too high of an iteration gain and cause your iterations to diverge, decrease the iteration gain and go back to a previous drive file using the Drive File Open button.

Lower iteration gain and tighter response error tolerance both increase the number of iterations that you need to perform. A formula for the number of iterations as a function of iteration gain to achieve a given percentage error is:

$$\#iterations = \frac{\ln(percent\_error/100)}{\ln(1-iteration\_gain)}$$

Although this formula is valid only for perfectly linear systems, it is a useful approximation for nonlinear systems as well.

Step 8: **Start the iteration.** Hit the **Start** button on the OLI Panel. If this is Iteration 0 and you had OLI create the initial drive file for you, there will be no motion because the drive file is zero; otherwise motion will begin. We recommend that you watch the desired and response in the Digital Oscilloscope during the iteration to verify that motion is at acceptable levels. If you don't like what is happening, hit the Abort button on the OLI Panel to immediately terminate the iteration.

Step 9: **Examine the results of the iteration.** After each iteration, take time to look at the results of the iteration displayed in the Iteration Log. Verify that errors are decreasing. Iteration is complete when the errors have not significantly decreased for several iterations. Look carefully at max and RMS drive level figures; these tell you how large the motion will be on the next iteration. If these numbers seem unreasonably large, do not proceed to the next iteration or you may destroy your specimen and damage your machine.

If the errors are increasing from iteration to iteration, the iteration process is diverging. Divergence problems are almost always due to one of two reasons:

- The iteration gain is too high for the level of nonlinearity in the system. Lower the iteration gain, and go back a few iterations in the drive file sequence, especially if the amplitude of the response has built up to a level that exceeds the desired, because OLI has a much easier time scaling up to the desired level rather than scaling down to it. Use the Drive File Open button to call in a previous drive file.

- The inverse transfer function has been inadequately or improperly trained. Go back to AIC and retrain or refine its inverse transfer function.

If the errors are large but neither increasing nor decreasing on average, you may be at a physical velocity or force limit of your test system. There is nothing you can do in this case except accept the errors as they are, or decrease the amplitude of your desired waveform and start over.

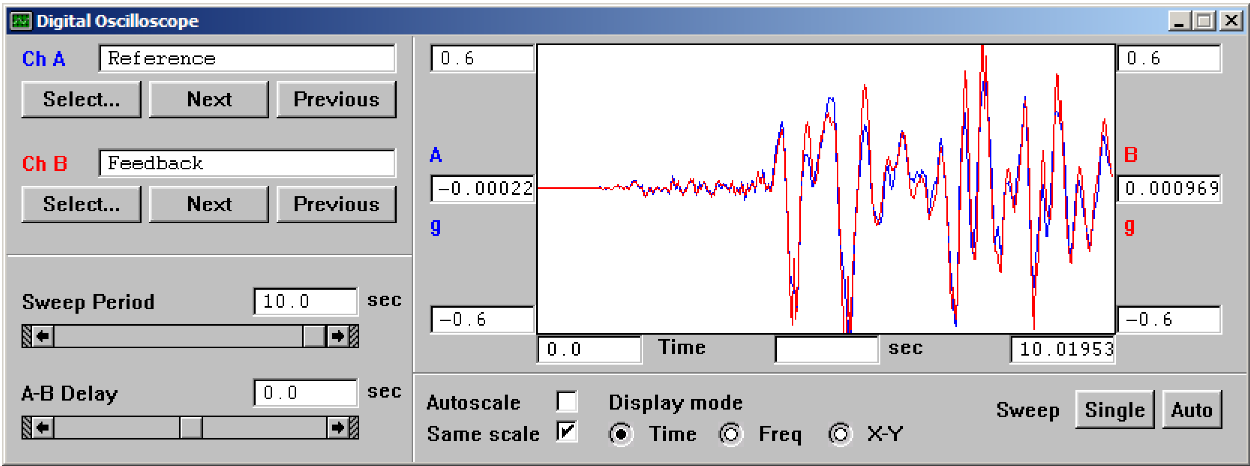
Step 10: Turn off OLI (when finished with the final iteration). On the Main Panel, first hit the **Stop** button to zero the master span. Then disable OLI. AIC will be automatically disabled as well.

The end product of the iteration process is the final drive file; all other drive files can be discarded. You don't have to use the OLI Panel to play this file; the File Function Generator or Data Player can be used instead. However, if you want to monitor peak and RMS errors while playing the file, you can use the OLI Panel for file playout. In this case, turn on OLI in Frozen mode so that OLI does not advance to the next drive file in the iteration sequence but rather continues to play the selected drive file.

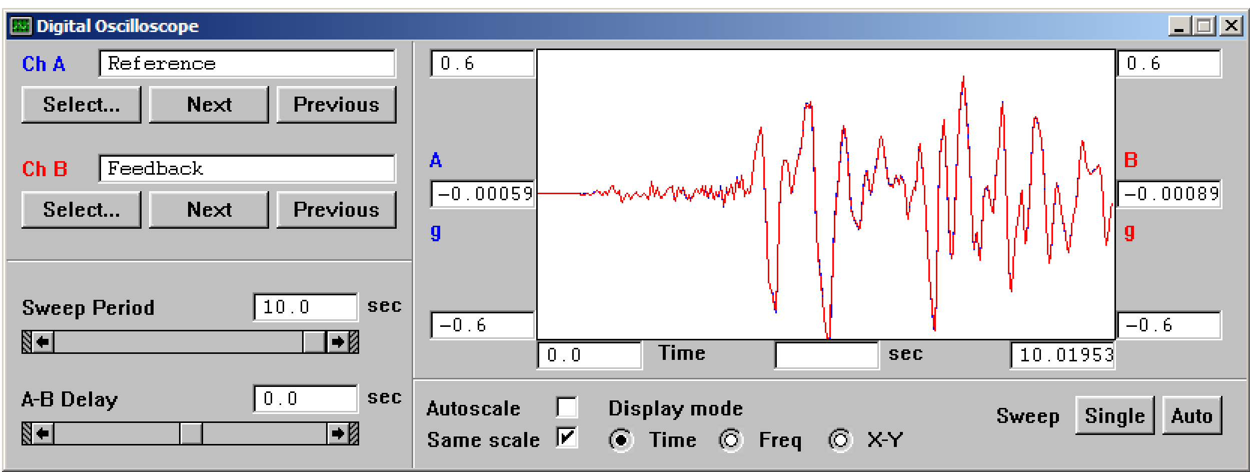
Viewing the Results

You can use the **Digital Oscilloscope** to monitor desired and response during the iteration process. You can also capture the response to file using the **Data Recorder** for post-test error analysis.

Below is an example showing desired and response time histories without OLI:



After several iterations of OLI, desired and response are almost perfectly overlaid:



Section 7

Maintenance Procedures

The test system demands periodic, routine maintenance to continue to provide optimum system performance. This section contains lists of recommended preventive maintenance procedures for the test system and a system maintenance log. For corrective maintenance information, refer to the appropriate product manual in the system Reference Manual or contact MTS Systems Corporation.

A seismic test system is a highly complex electromechanical system requiring maintenance by skilled personnel. A thorough understanding of the system's nature should be achieved by reading the system manuals and studying the machine before any maintenance procedure is begun.

Due to the size and weight of a seismic test system, many repair or maintenance procedures require the use of heavy machine rigging techniques. This manual is not intended to be a primer in this area and assumes a knowledge of such techniques and the use of personnel skilled in rigging.

General Inspection Criteria

Before performing any maintenance routine, read the safety practices in Section 2 of this manual and the maintenance procedures in the applicable product manuals (contained in the system Reference Manual). Any system component not specifically discussed in this section or in the system Reference Manual should not be adjusted or tampered with. Consult MTS Systems Corporation about any problems concerning adjustment of such components.

⚠ WARNING

The Safety Practices section of this manual contains information that can help maintenance personnel minimize hazards which can be encountered during system maintenance.

Failure to observe the Safety Practices described in this manual prior to attempting the following maintenance procedures can result in injury to personnel and/or damage to equipment.

Ensure that all persons involved in the maintenance of the equipment read the Safety Practices section of this manual.

Because each seismic system is a unique installation, the experience basis is very limited on many of the design decisions made during construction. For this reason, and in order to maintain a safe system, it is very important to contact the MTS Service Department immediately if any of the following conditions are noted:

- Excessive nitrogen leakage.
- Any bolt or nut fastener failure or any sign of loss of bolt preload, even if the bolt appears to be defective or if the system has been operated with insufficient torquing through oversight.
- Signs of cracking or slipping of any structural members.
- Any operation or maintenance procedure that may have accidentally overloaded any structural component.
- Any loss of system control or unexplained tripping of the limit detector interlocks.
- Any unexplained loss of hydraulic fluid from the system reservoir.

System Operating Inspections

Check for normal system operation whenever the system is run. In addition to the operation safety checks listed in Section 2 of this manual, routine operation inspections should consist of checks for the following:

- Fluid level in the hydraulic power supply reservoir is normal (as indicated on the reservoir fluid level gage).
- Nitrogen precharge in the accumulators is within ±20% of posted pressure.
- No noises (i.e., creaking or clunking) are coming from the actuator swivels.

Preventive Maintenance Procedures

Most test system maintenance is limited to routine inspections for signs of obvious component failures, replacement of oil filters, and maintenance of the correct nitrogen precharge for the accumulators. The following subsections briefly describe specific maintenance tasks. Refer to the appropriate product manual (in the system Reference Manual) for detailed maintenance procedures.

The time between maintenance intervals may require re-evaluation and may change from the specified interval due to experience gained after the system has been in operation.

Before Starting a Test

General inspection before starting a test. Inspect the area under the table for damage or obstruction. (e.g., forgotten tools, etc.).

After Completing a Test

General inspection after completing a test. Inspect the system for obvious signs of cracking, buckling, loose bolts, leaks, or other conditions requiring maintenance or repair. If any of these conditions are found, contact MTS Systems Corporation.

Check overtravel bumper assemblies. If, during a test operation, any major impact of the bumper assemblies occurs, check the condition of the bumper assemblies. Replace if necessary.

Check actuator and attachment hardware. Check the actuator and attachment hardware for any sign of damage. Correct any problem that exists.

Inspect hydraulic components. Inspect the hard line, pressure sensors, gages, and hose connections for signs of leakage. Correct any problem that exists.

Inspect all bolts. Inspect bolts for obvious signs of looseness or structural failure. Correct any problem that exists.

Check hydraulic fluid level, color and odor. Check the fluid level in the HPS sight gage to ensure that it is within the correct operating range. A below normal level would indicate a loss of hydraulic fluid. If below normal, inspect the system for leakage, correct the problem, and refill it to the proper level. Check the fluid color and compare it to the first test sample taken after initial system installation. Check the smell of the hydraulic fluid. If necessary, replace the hydraulic fluid.

[Hydraulic Power Supply Product Manual]

Check HPS high pressure filter. Replace the HPS high pressure filter elements whenever the DIRT ALARM indicator mounted on the base of each high-pressure filter housing points to CHANGE (red or yellow zone). In addition, if the hydraulic oil is changed, replace the HPS high pressure filter.

[Hydraulic Power Supply Product Manual]

Check HPS low pressure filter. Replace the HPS high pressure filter element whenever the FILTER DIRTY indicator on the HPS front control panel lights. In addition, if the FILTER indicator on the software main panel lights or the hydraulic oil is changed, replace the HPS low pressure filter.

[Hydraulic Power Supply Product Manual]

Check HSM pilot pressure filter. Change the HSM pilot pressure filter whenever the controller senses a dirty pilot pressure filter condition. In addition, if the hydraulic fluid is changed, replace the pilot filter.

[Hydraulic Service Manifold Product Manual]

As Required

Check backlash on split-jaw swivel assemblies. Check the backlash on the actuator swivel assemblies after the first four to five hours of use and as often as necessary thereafter.

[Swivel Product Manual]

Clean actuator piston rod. Clean the exposed area of the hydraulic actuator piston rod.

[Actuator Product Manual]

Replace actuator seals. Replace the piston rod seals whenever leakage occurs or whenever the actuator has been disassembled.

[Actuator Product Manual]

Clean parking cylinder piston rods. Clean the parking cylinder piston rods. Reseal as necessary.

Monthly

Check accumulator precharge levels. Check precharge of all accumulators. If the accumulator pressures are outside of the accepted levels, charge or discharge the accumulators.

[Accumulator 111 Product Manual]

[Hydraulic Service Manifold Product Manual]

Check hoses. Check hoses for wear or damage.

Every 1500 Operating Hours

Analyze hydraulic fluid sample. Take a sample of the hydraulic fluid and have it analyzed. Replace the fluid if necessary.

[Hydraulic Fluid Care Guide]

Every 6 Months

Run the system. Start the system and allow it to reach operating temperature on a monthly basis. This action drives moisture out of the system and lubricates components that may have drained while inactive.

Check regulated pressure valve. Check the setting of the regulated pressure valve on the HPS.

[Hydraulic Power Supply Product Manual]

Check actuator friction. Measure the friction in the system by monitoring the delta P signal with a ±125 mm program at 0.1 Hz.

Clean or replace the HSM pilot pressure filter. Clean or replace the HSM pilot pressure filter element on the parking frame.

[Hydraulic Service Manifold Product Manual]

Every Year

Check calibration of accelerometer and LVDT. Check the calibration of accelerometer and LVDT.

[User's Manual, Section 8, Calibration]

System Maintenance Log

The system maintenance log is a tool to use in recording and tracking maintenance. The maintenance interval/date of maintenance entries should be made when the maintenance is actually performed. An example maintenance log is illustrated below.

SYSTEM MAINTENANCE LOG

System #2
Page 1 of 3

Instructions: When maintenance is performed, fill in date, operating hours (from running time meter), and/or other appropriate maintenance interval

PROCEDURE	RECOMMENDED INTERVAL	MAINTENANCE INTERVAL / DATE OF MAINTENANCE							
Check hyd. grip pressure supply	Weekly	- / 9-9	- / 9-16	- / 9-23	- / 9-30	- / 10-7	- / 10-14	- / 10-21	- / 10-28
		- / 11-4	- / 11-11	- / 11-18	- / 11-25	- / 12-2	- / 12-9	- / 12-16	- / 12-23
		- / 12-30	- / 1-6	- / 1-13	- / 1-20	- / 1-27	- / 2-3		
Check s/v balance	100 operating hours	0 / 9-9	100 / 9-23	200 / 10-9	292 / 10-21	380 / 11-4	500 / 11-24	590 / 12-9	685 / 12-23
		800 / 1-8	900 / 1-17	994 / 1-27					
Check hydraulic hoses	Monthly	- / 9-9	- / 10-7	- / 11-14	- / 12-2	- / 1-6	- / 2-3		
Clean air filter	Monthly	- / 9-9	- / 10-7	- / 11-14	- / 12-2	- / 1-6	- / 2-3		
Check HSM accum. precharge	Monthly	- / 9-9	- / 10-7	- / 11-14	- / 12-2	- / 1-6	- / 2-3		
Purge air from hyd. lifts	As req'd	- / 9-9	- / 9-23	- / 10-21	- / 12-2				
Clean actuator rods	As req'd	- / 9-9	- / 9-23	- / 10-7	- / 10-21	- / 11-4	- / 11-18	- / 12-2	- / 12-6
		- / 12-30	- / 1-13	- / 1-27					
Check HPS fluid	500 operating hours	0 / 9-9	500 / 11-24	994 / 1-27					

LA-FM029

Example System Maintenance Log

It may be helpful to maintain separate logs for maintenance procedures that are required weekly, monthly, yearly, etc.

Section 8

Calibration and Tuning

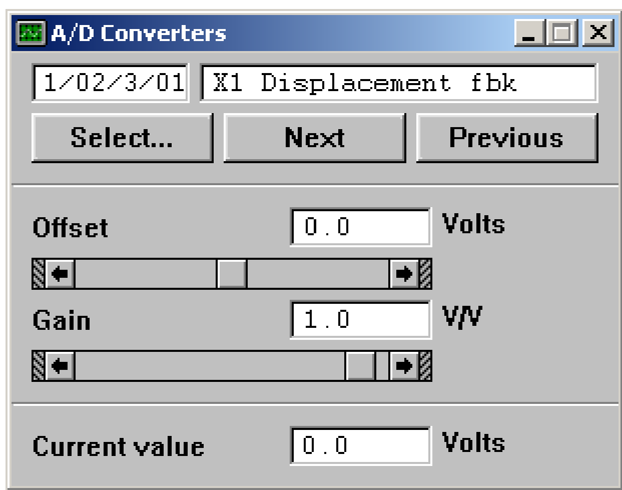
Overview

The *Calibration* section explains how to calibrate devices using the following panels:

- A/D Converters
- AC Conditioners
- DC Conditioners

The *Tuning* section explains how to tune the 256 Valve Inner Loop and Three-Variable Control (TVC).

A/D - D/A Converters Calibration



A/D Converter Procedure

To calibrate an A/D converter, take the following steps:

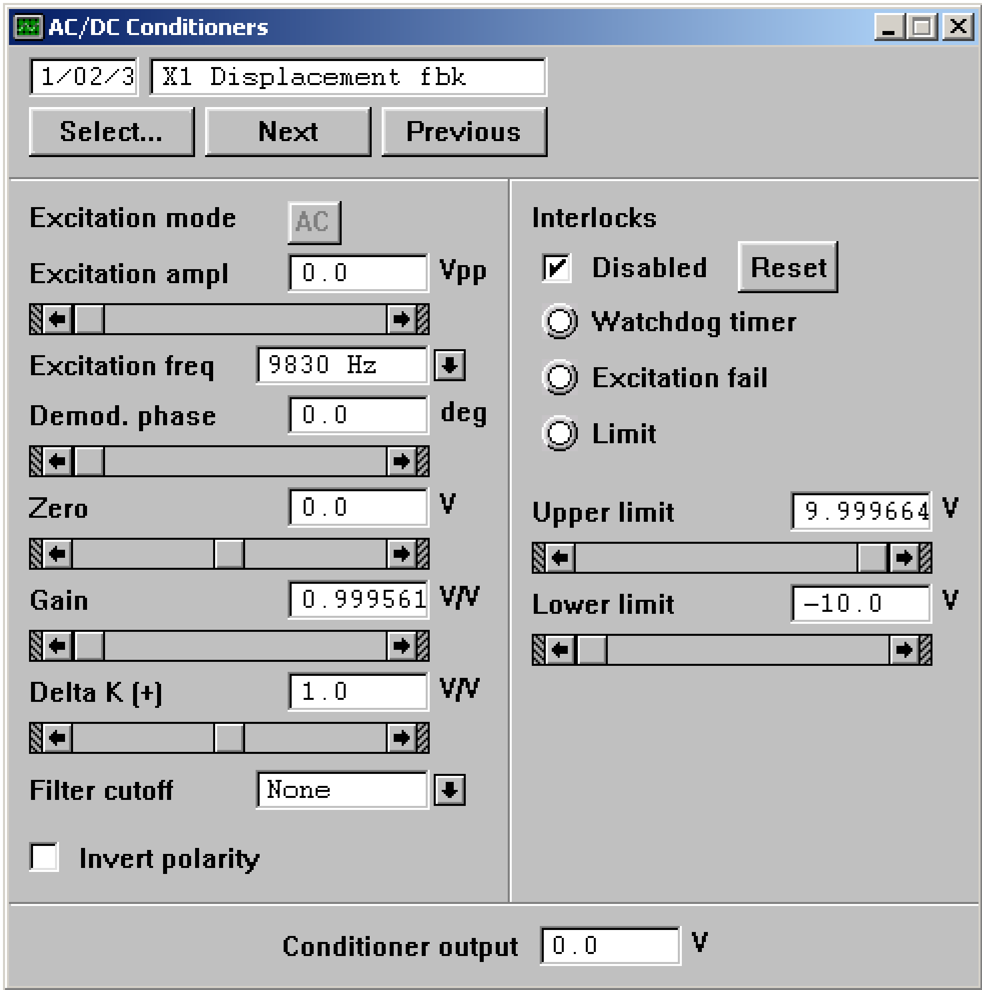
1. Select the desired A/D channel.
2. Ground the input signal.
3. Adjust the **Gain** control to +1.00.
4. Adjust the **Offset** control until the current value reads 0.00V.
5. Input a DC signal between 0V and 10V from a calibrated voltage source such as a D/A or a power supply.

6. Adjust the **Gain** control until the current value displayed matches the value of the signal input from the calibrated voltage source.
7. Remove the calibrated voltage source.
8. When the calibration procedures are completed, select Save Calibration from the **Calibration** menu on the main panel to save the new calibration settings.

D/A Converter Procedure

No D/A calibration procedures should be necessary. Consult MTS Systems Corporation if calibration concerns arise.

AC Conditioner Calibration



Calibration (for a stroke channel) means adjusting a known voltage to correspond to a known displacement.

The AC Conditioner uses a reactive type transducer such as a linear variable differential transformer (LVDT). This transducer measures bidirectional displacement from a zero reference position.

To calibrate an AC Conditioner stroke channel, complete the following steps:

NOTE : Turn on the console and allow the modules to warm up properly (approximately 5 minutes) before you make any electrical adjustments.

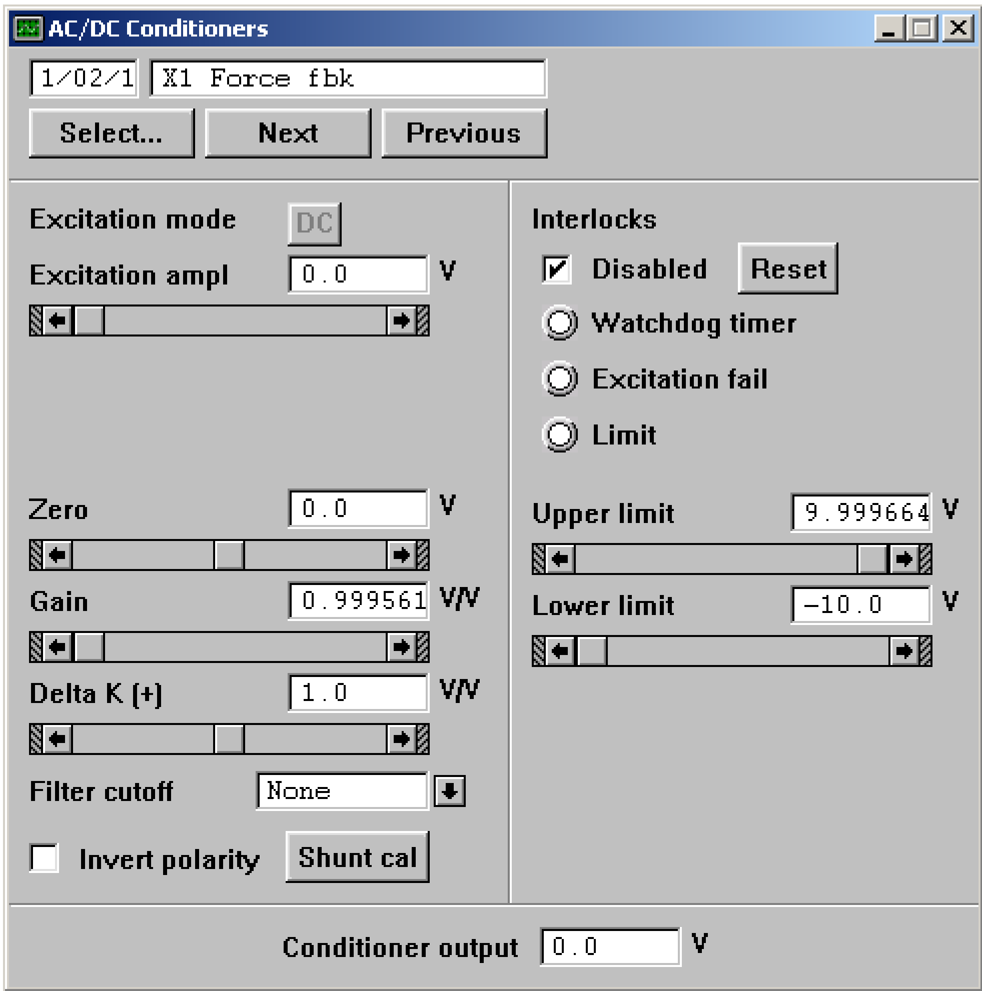
1. Select the **Conditioners** option from the **Calibration** menu on the main panel.
2. Select the AC Conditioner channel.

3. Adjust the **Gain**, **Excitation**, and **Delta K** controls to the respective values listed on the original calibration sheets, or set **Gain** to approximately 3 V/V, **Excitation** to 10.000 Vpp, and **Delta K** to 1.000 V/V (these are the approximate midpoint values for each control).
4. Select **HSM Lo** on the main panel. Adjust the **Setpoint** control (on the main panel) to fully retract the actuator without positioning it in the end cap.
5. Remove the Hydraulics.
6. Adjust the **Demod phase** to maximize the output of the conditioner.
7. Apply the Hydraulics.
8. Adjust **Setpoint** to obtain a reading of zero from the conditioner.
9. Connect a displacement measurement device to the actuator rod.
10. Move the **Setpoint** to move the actuator to obtain –10.000 Volt from the conditioner.
11. Adjust conditioner **Gain** until the displacment measurement device reads the correct full-scale displacement.
12. Repeat steps 8-11 until zero and full-scale are within desired tolerance.
13. Adjust **Setpoint** (on the Main panel) to +100% until the conditioner output is 10.000 volts.
14. Adjust **Delta K (+)** (on the AC Conditioners panel) until the displacement measurement device reads the correct positive full-scale displacement.
15. Plot the actuator linearity by recording the conditioner output values from the transducer conditioner for ±20%, ±40%, ±60%, ±80%, and ±100% of full-scale.
16. For example, adjust **Setpoint** (on the Main panel) for a dial indicator readout of 15 mm (+20%). Record the conditioner output values on your transducer calibration sheet. Repeat this step for ±20%, ±40%, ±60%, ±80%, and ±100% of full-scale displacement.

NOTE: The accuracy tolerance (linearity) should be ±1% of full-scale. Therefore, in the example above, 15 mm should indicate a range between 1.90 to 2.10 Vdc on the conditioner output. If not, return to step 1.

17. When the AC Calibration procedures are completed, select Save Calibration from the **Calibration** menu on the main panel to save the new calibration settings.

DC Conditioner Calibration



The DC Conditioners are used for different types of feedback: force and acceleration. Force is measured using a differential pressure cell and acceleration is measured using an accelerometer. Each has its own calibration procedure

Force Transducer Calibration

To calibrate a DC Conditioner for use with a differential pressure cell:

NOTE: Turn on the console and allow the modules to warm up properly (approximately 5 minutes) before you make any electrical adjustments.

1. Select the **Conditioners** option from the **Calibration** menu on the main panel.

2. Select the DC Conditioner channel for the force feedback.
3. Disconnect the differential pressure cell from the actuator, being careful to note its orientation.
4. Attach an appropriate, calibrated pressure source to the differential pressure cell input labeled P1. The pressure source must meet the capacity of the differential pressure cell and have a higher accuracy than the differential pressure cell. (MTS recommends using a dead weight pressure tester).
5. If necessary, adjust the **Excitation** and **Gain** controls to the respective values listed on the original calibration sheet.
6. Apply a pressure as close to 100% capacity of the system as possible. Then apply zero pressure and adjust the **"Zero "** value on the DC Conditioner panel until the **"Conditioner output "** equals 0V. Repeat step 6 two more times.
7. Apply a known exact pressure at 80% capacity of the system. Calculate the ideal DC conditioner output value for this pressure and compare it with the actual DC Conditioner output value. The actual value should be within the permissible variation of the ideal calculated value. (Refer to the original calibration sheet for the permissible variation). If the actual value is not within the permissible variation, adjust the **Gain** setting on the DC Conditioner panel until it is.
8. Apply pressures equal to 20%, 40%, 60%, and 100% capacity of the system. Monitor the conditioner output values to make sure these values are within specification. (Refer to the original calibration sheet for the permissible variations).
9. Readjust the 80% gain if any values are out of specification by going back to step 7.
10. Disconnect the pressure source from the differential pressure cell input labeled P1 and connect it to the differential pressure cell input labeled P2.
11. Apply a known exact pressure at -80% capacity of the system. Calculate the ideal DC conditioner output value for this pressure and compare it with the actual DC Conditioner output value. The actual value should be within the permissible variation of the ideal calculated value. (Refer to the original calibration sheet for the permissible variation). If the actual value is not within the permissible variation, balance the error between the two sides of the differential pressure cell (P1 and P2) by readjusting the gain appropriately.

12. If desired, repeat the measurements for ±20%, ±40%, ±60%, ±80%, and ±100% of fullscale. Record the conditioner output values on your transducer calibration sheet.
13. When the DC Conditioner calibration procedures are completed, select **Save Calibration** from the Calibration menu on the main panel to save the new calibration settings.
14. When the calibration is complete, disconnect the pressure source from the differential pressure cell, and reconnect the differential pressure cell to the actuator according to its original orientation.

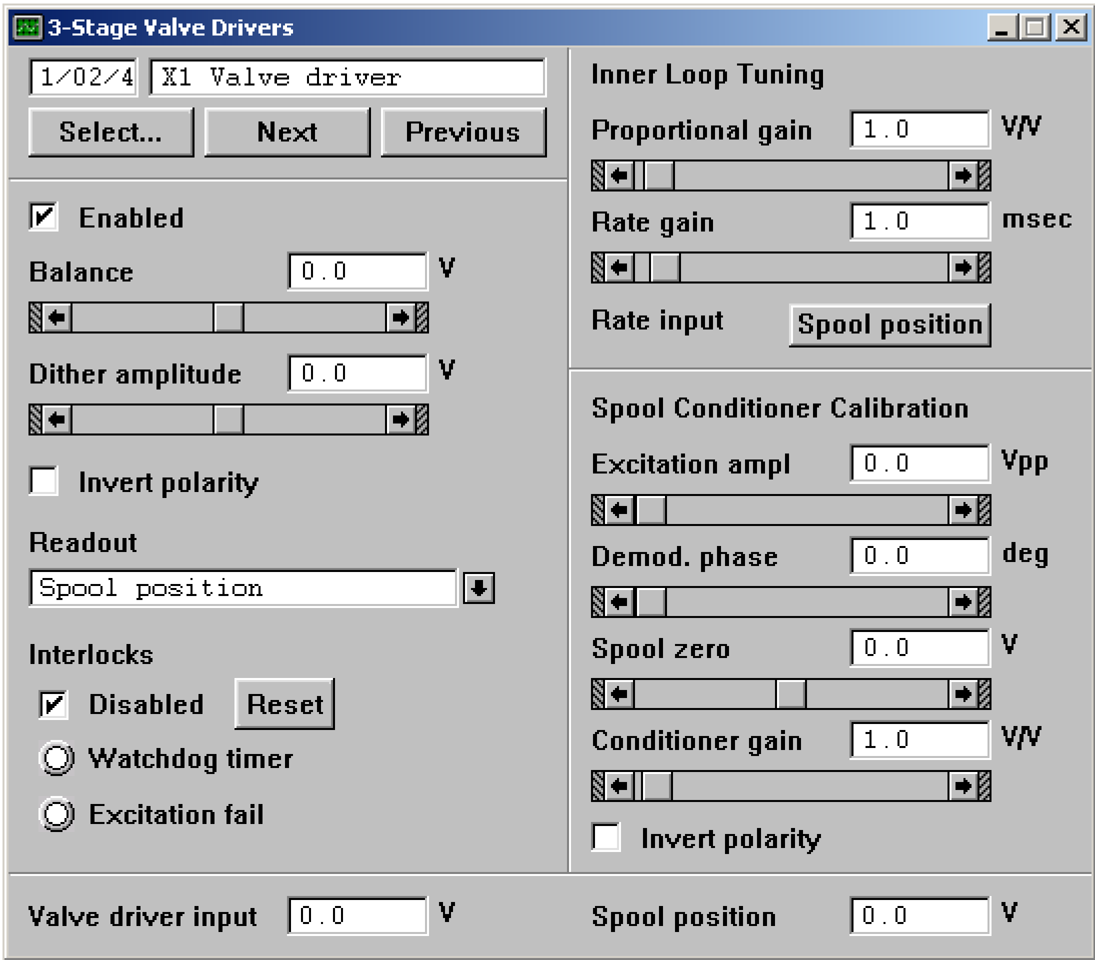
Acceleration Feedback Calibration

To calibrate the DC Conditioner for use with an accelerometer:

NOTE: Turn on the console and allow the modules to warm up properly (approximately 5 minutes) before you make any electrical adjustments.

1. Select the **Conditioners** option from the **Calibration** menu on the main panel.
2. Select the DC Conditioner channel for the acceleration feedback.
3. Mount a "standard" or recently calibrated accelerometer to the table in close proximity to the accelerometer which is being calibrated and connect its output to channel 1 of a two channel dynamic signal analyzer or other device that provides narrow band AC voltage measurement capability or, if available, mount the accelerometer to be calibrated onto a portable accelerometer calibration stand with a built-in exciter.
4. Adjust the **Zero** value on the DC Conditioner panel until the "**Conditioner output** " equals 0V.
5. Apply a known acceleration to the accelerometers.
6. Connect channel 2 of the two channel dynamic signal analyzer or other device to the tip jack outputs labeled OUT2 and COM on the front panel of the DC conditioner board.
7. Adjust the gain level on the DC Conditioner board until the peak to peak output voltage of the DC Conditioner (channel 2) equals that of the "standard" accelerometer (channel 1).
8. When the DC Conditioner calibration procedures are completed, select **Save Calibration** from the Calibration menu on the main panel to save the new calibration settings.
9. Remove the calibration equipment and restore system to its normal configuration.

256 Valve Inner Loop Tuning



A programmable digital controller controls the position of the third stage pilot valve spool, which in turn controls the flow of hydraulic fluid to the actuator. Valve spool position is measured using a LVDT (linear variable differential transformer). Inner loop tuning consists of setting the LVDT conditioner settings, and tuning the analog controller servo loop gains.

Equipment

The following equipment is required for inner-loop tuning.

493 I/O Carrier service cables (P/N's 100-026-162 and 100-026-163)

Spool Conditioner Gain

An LVDT is used to measure the position of the third stage pilot spool in a 3-stage servo valve. The 3-stage valve driver card provides excitation and conditioning for this transducer. The first step in inner-loop tuning is setting the spool conditioner adjustments.

1. Open the **3-Stage Valve Drivers** panel.
2. Attach the service cable to the I/O Carrier card housing the 493.15 valve driver card. The position of the valve driver card in the carrier card determines which channel to use on the service cable. (see the Valve Drivers Panel to determine the chassis and slot number of the 493.15).
3. Attach the appropriate service cable channel output to an unused User A/D input on the controller.
4. Turn hydraulic power ON. This provides pilot pressure to the 3-stage servo valves while preventing the actuator from moving.
5. Set the Spool Conditioner adjustments to the following initial values:
6. Excitation 10 Vpp
7. Demodulator Phase 22.5 deg
8. Spool Zero Offset 0 V
9. Conditioner Gain 10.0 V/V
10. Conditioner Polarity Inverted
11. Select **Spool Position** in the Rate input readout pop-up menu. Monitor this signal using the User A/D input selected earlier.
12. Set the Inner Loop Tuning **Proportional gain** to zero. This will allow the third stage pilot spool to float into one of the end caps.
13. Adjust the **Demodulator phase** to maximize the Spool Position feedback value.
14. Adjust the **Conditioner gain** so that the amplitude of the spool position feedback is 10 volts. The spool position feedback may be ±10 volts depending on the mechanical bias of the servo valve.
15. Use the valve **Balance** to drive the servo valve into the other end cap (change the sign of the spool position feedback). If the amplitude of the spool position feedback exceeds 10 volts, lower the conditioner gain setting until spool position feedback reads 10 volts.

Servo Gain Tuning

The digital controller has programmable proportional and derivative gain terms that are set using the valve driver panel.

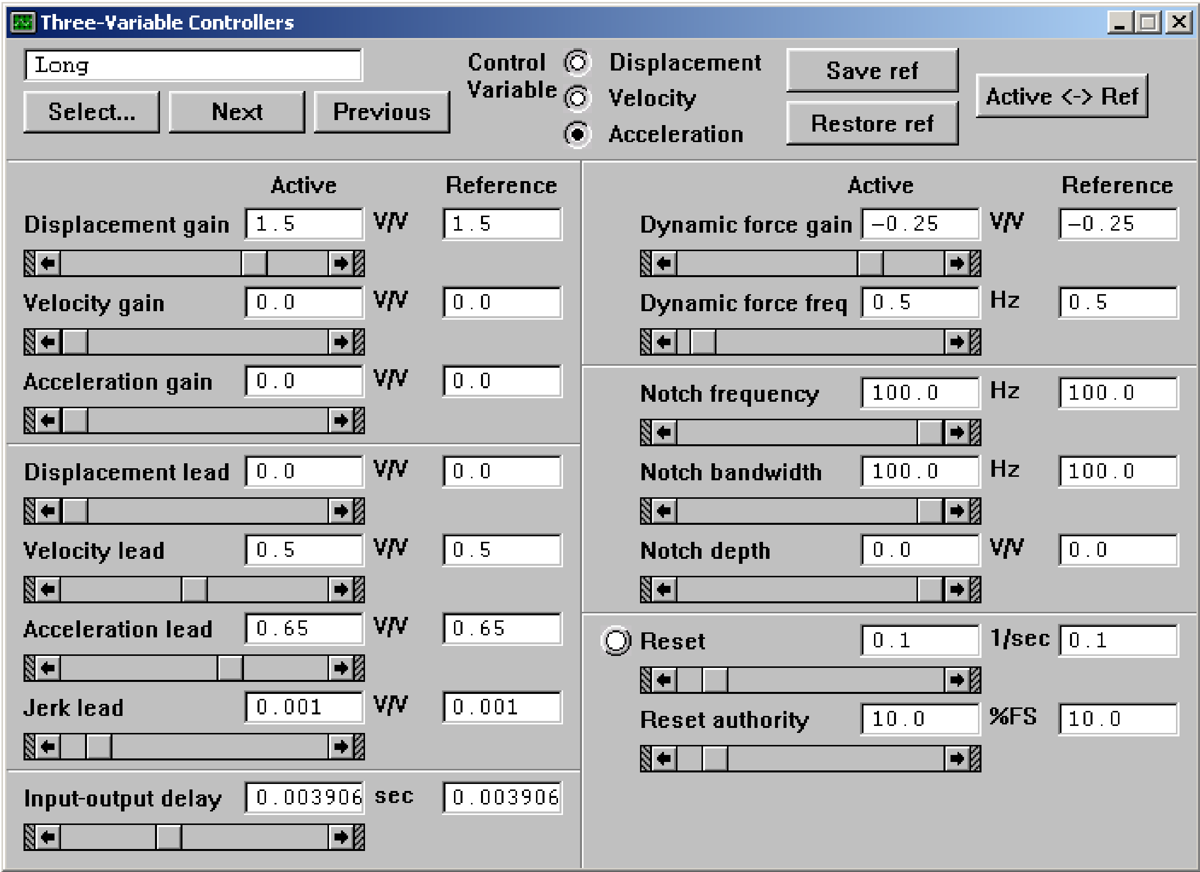
1. Open the **3-Stage Valve Drivers** panel.
2. Attach the service cable to the I/O Carrier card housing the 493.15 valve driver card. The position of the valve driver card in the carrier card determines which channel to use on the service cable. (see the Valve Drivers Panel to determine the chassis and slot number of the 493.15).
3. Attach the appropriate service cable channel output to an unused User A/D input on the controller.
4. Use the Oscilloscope to monitor the selected User A/D input.
5. Turn hydraulic power ON. This provides pilot pressure to the 3-stage servo valves while preventing main pressure from reaching the machine.
6. Select **Spool position** in the Rate input readout pop-up menu of the valve driver panel.
7. Set the Inner Loop Tuning **Proportional gain** to 0.0 and the **Rate gain** to 0.0.
8. Open the **Function Generator** panel, set up square wave to 1 Hz. and start with small amplitude such as 5 to 10%.
9. Use the oscilloscope to view the spool position feedback signal. On the **Valve Driver** panel, raise the proportional gain until the spool begins to overshoot.
10. Adjust the valve **Balance** until the overshoot is the same in the positive and negative directions.
11. Raise the **Rate gain** to dampen out the overshoot. Raise the **Proportional gain** to achieve overshoot, then dampening out the overshoot using rate gain. Continue this iterative cycle until the feedback begins showing some sawtooth waveform or instability occurs. Back off proportional and derivative (rate) terms for clean rise and corner move to horizontal.

Spool Zero Adjustment

Ideally, setting the valve drive signal to zero should result in no motion in the system and minimum oil flow. Realistically, all three stage valves have a little mechanical/electrical bias that must be adjusted out. This is done using the spool zero adjustment and adjusting the spool LVDT position.

1. Open the **Digital Meter** panel and select the valve drive signal.
2. Turn the hydraulic power and HSM to **High**.
3. Adjust the **Spool zero** value in the valve driver panel to zero.
4. Loosen the locknut on the spool LVDT and slowly move the LVDT in or out until the valve drive signal displayed by the digital meter is zero. Tighten the locknut on the LVDT such that the valve drive signal remains as close to zero as possible.
5. Adjust the spool zero value in the valve driver panel to a value that results in zero valve drive.

Three-Variable Control (TVC) Tuning



Three-Variable Control (TVC) is what is known in control theory literature as *state variable control*, with additional special features. The three state variables that TVC can control are displacement, velocity, and acceleration. It is a common misconception that all three state variables are controlled simultaneously. The truth is that only one state variable is the primary control variable, with the others serving only as compensation signals to improve damping and stability.

During the tuning procedure, you will be making extensive use of the following user interface panels:

- Random Function Generator Panel
- Observer Panel
- Three-Variable Control Panel
- Resonance Compensator Panel

A description of these panels will be presented first, followed by basic step-by-step TVC tuning procedures for displacement, velocity, and acceleration control modes. Lastly, some advanced topics such as the tuning of notch filters to combat resonances and antiresonances will be discussed.

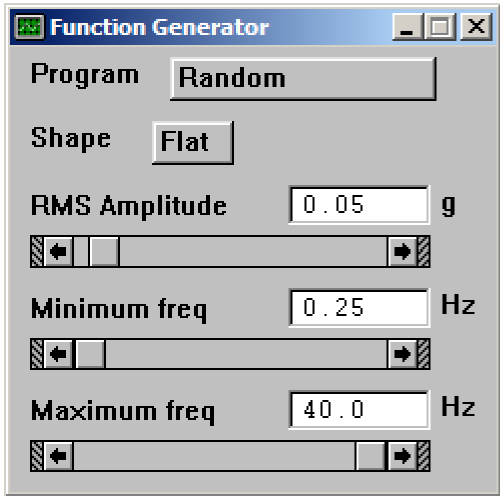
It should be emphasized that control tuning is an art. Each control system is different, having its own unique blend of dynamics and peculiarities. Your system may tune differently than the system used to generate the examples presented here. With enough practice you will learn how to modify the procedures presented here to fit your particular case.

One word of caution: When tuning, *do not move a gain slider bar until you first determine its minimum and maximum limits*. Otherwise you may inadvertently scroll the gain to a large value, causing instability that could destroy your specimen and damage your test machine. Do not assume that the limits are reasonable values; check them yourself. You can do this by clicking on the striped regions to the left and right of the scrolling arrows as show below:

The minimum or maximum limit is then displayed in the slider bar's value edit display box where you can change it if necessary.

The minimum or maximum limit is then displayed in the slider bar's value edit display box where you can change it if necessary.

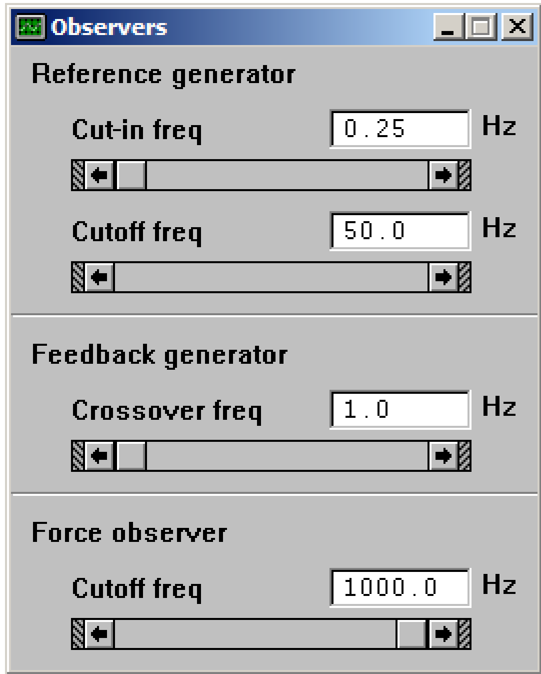
Random Function Generator Adjustments



Because TVC tuning is done almost exclusively in the frequency domain, the Random Function Generator is used to excite the system so that good transfer function estimates can be obtained.

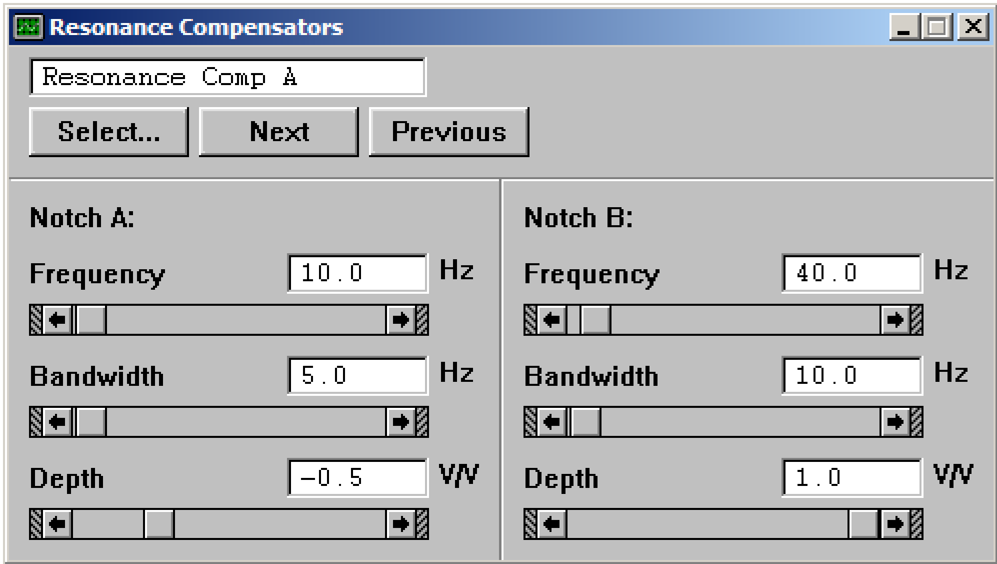
The Random Function Generator consists of a uniform distribution random number generator followed by a bandpass filter. This filter has four parameters adjustable from the Random Function Generator Panel:

Observer Panel Adjustments

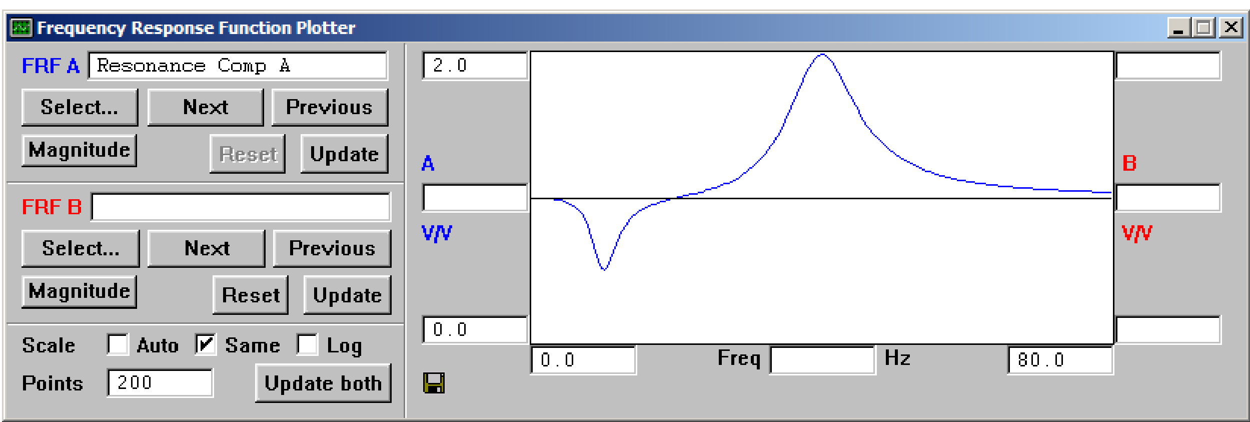


The Observers Panel is where adjustments for the Reference Generator, Feedback Generator, and Force Observer are made (the term "observer" is control theory terminology for a special-purpose filter that computes a feedback signal):

Resonance Compensator Panel Adjustments



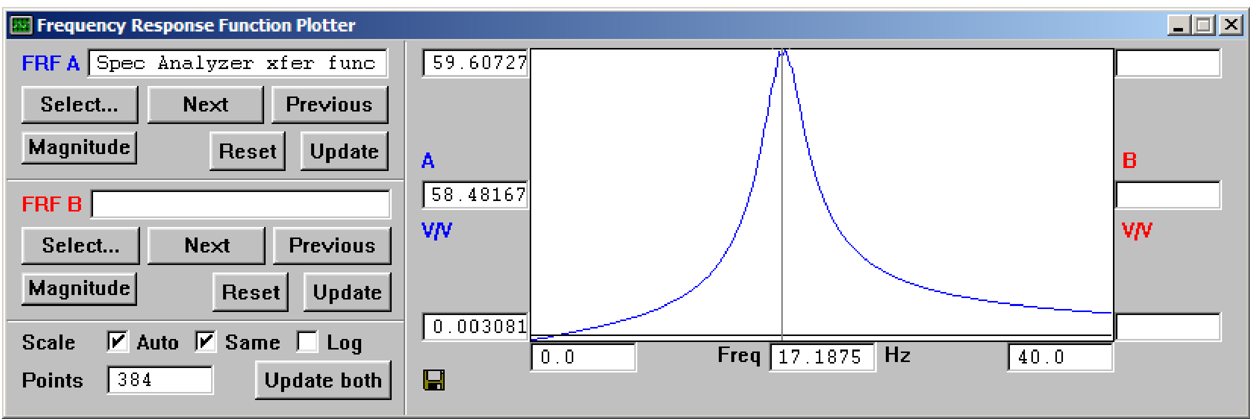
The Resonance Compensator consists of four identical notch filters, grouped into two pairs for user interface purposes because resonances usually come in resonance/antiresonance pairs. Like the TVC notch filter, the frequency response of the Resonance Compensator notch filters can be viewed in the FRF Plotter. For the tuning shown in the panel above, the frequency response looks like this:



Determining the Oil Column Natural Frequency

Before starting the tuning process, it is useful to know the value of the oil column natural frequency. Certain gains have affect below while others have affect above this frequency; knowing on which side a deficiently-tuned region of frequency response lies suggests which gain adjustment will yield the most improvement. Furthermore, if the oil column natural frequency lies significantly above the maximum frequency of operation, tuning is simplified because some of the tuning steps described in later sections can be omitted.

To measure this frequency, measure the transfer function between the controller output and the force feedback using the Spectrum Analyzer. The oil column natural frequency lies close to the peak of the magnitude response; in the example shown below, this frequency is approximately 17 Hz.



Displacement Control Tuning

While tuning, keep in mind these points, which apply not only to displacement control mode but to all control modes:

As gains are increased, the valve command may become large to the point of saturation at ±10 volts. When this happens, the frequency response measured by the Spectrum Analyzer can be misleading. Always look at the controller output on the Digital Oscilloscope to verify that the valve command is not saturating. If it is, you may have to either reduce the gain or reduce the reference amplitude.

While tuning you will mostly be looking at the frequency response in the FRF Plotter. As you approach a satisfactory tuning, i.e., one that yields a frequency response near unity, you should look at the reference and feedback on the Digital Oscilloscope to verify that they are reasonably similar. This is because it is possible to have a frequency response near unity yet have dissimilar reference and feedback, which can happen if there are nonlinearities at play or if the system has been tuned such that the phase response is nonlinear.

1. **Set up the Reference Generator.** Set the cutoff frequency to the maximum allowable value. Note that the cut-in frequency cannot be adjusted because it has no effect in displacement control mode.

2. **Set up the Random Function Generator.** Set the shape to "1/F^2" or "1/F", the minimum frequency to zero, and the maximum frequency according to the desired control bandwidth.

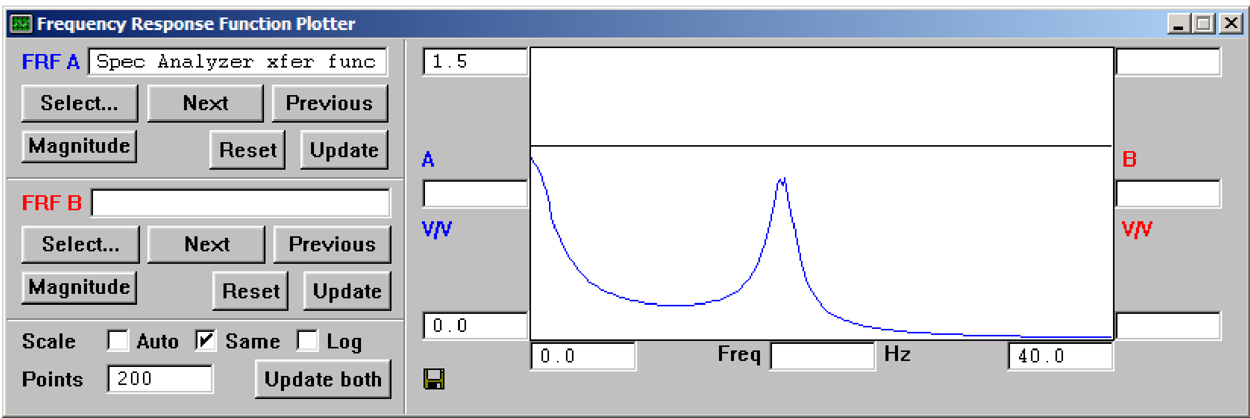
3. **Enter initial TVC and Resonance Compensator parameters values:**

TVC PARAMETERS	TVC VALUES
Displacement gain	1.0
Velocity gain	0.0
Acceleration gain	0.0
Feedforward gains	all zero
Input-output delay	0.0
Dynamic force gain	0.0
Dynamic force freq	0.5 Hz
Notch frequency	any value
Notch bandwidth	any value
Notch depth	0.0
Reset	0.0
Reset authority	5 %

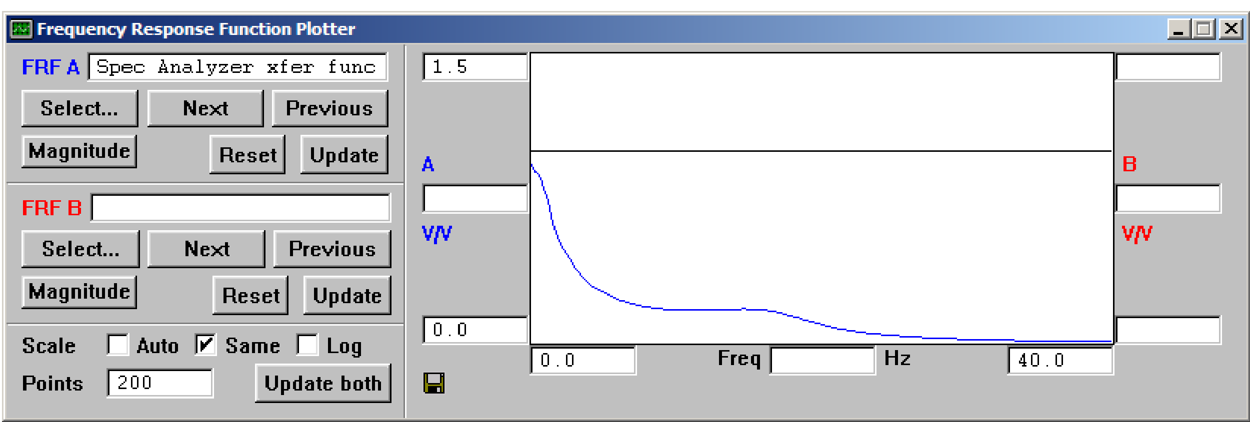
RESONANCE COMPENSATORS A & B PARAMETERS	RESONANCE COMPENSATORS A & B VALUES
Notch frequency	any value
Notch bandwidth	any value
Notch depth	0.0

4. **Run the Random Function Generator.** Press the Run button.

5. **Increase the displacement gain.** Increase the displacement gain until the frequency response is adequate at low frequencies, but without causing the oil column resonance to peak above unity magnitude, as shown below:



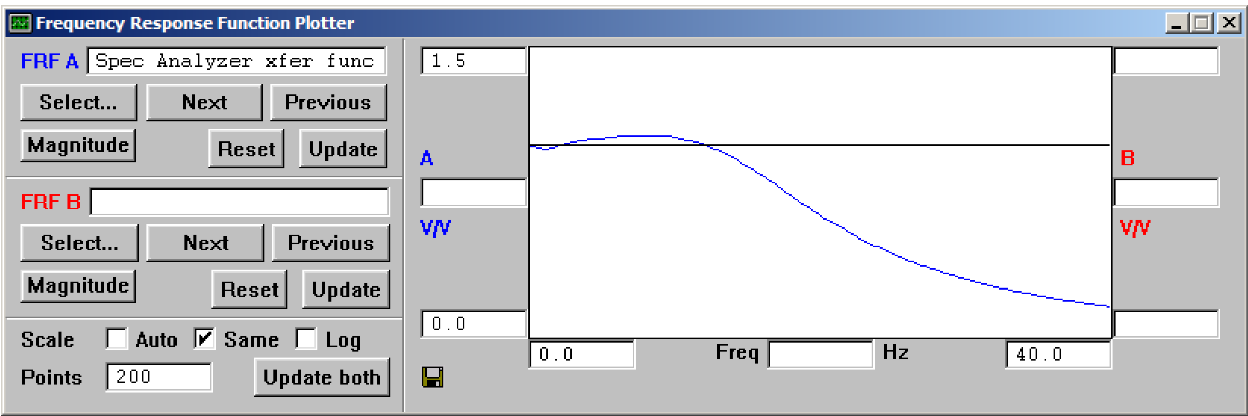
6. **Increase the dynamic force gain.** Increase the dynamic force gain until the oil column resonant peak is barely visible, as shown below:



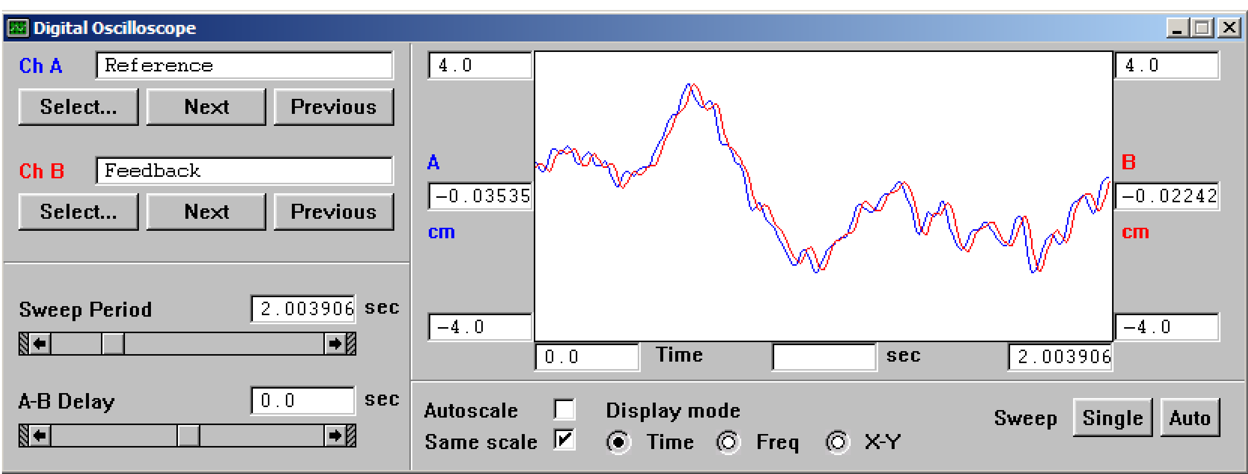
Note that if the force feedback is phased properly, the dynamic force gain will be negative, and increases in the negative direction result in more oil column resonance suppression (up to a point). It is easy to drive the system into instability by using too much of this gain, so be careful.

In systems without force feedback this gain parameter has no effect. Instead you can use the TVC notch filter to suppress the oil column resonance. This is discussed in a later section.

7. **Increase the velocity lead.** Increase the velocity lead to boost the frequency response below the oil column natural frequency. This will also boost the response at the oil column natural frequency, causing it to peak above unity magnitude. Increase the dynamic force gain (or deepen the TVC notch) to bring the response back down. The frequency response then should look like this:

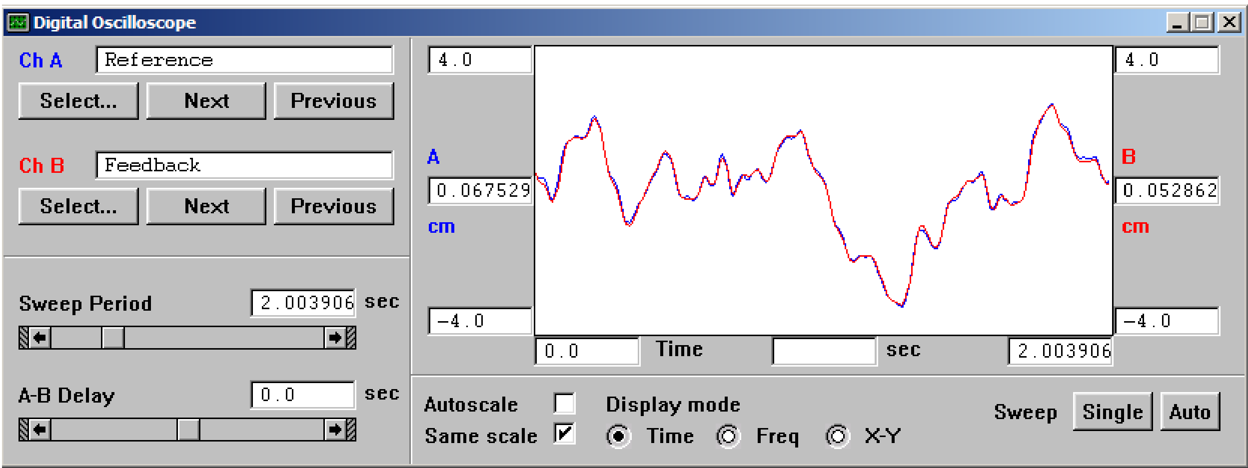


8. **Adjust the input-output delay.** Although the controller is now optimally tuned, there is a delay between reference and feedback, as shown in the time response below



This delay is inherent in all closed-loop control systems. Although the feedback is almost a perfect copy of the reference, the difference between the two waveforms is large solely because of the delay. This difference can be minimized by delaying the reference by an amount of time determined by the input-output delay adjustment so that it is aligned with the feedback for display and error calculation purposes. It has no effect whatsoever on stability or the quality of control.

To adjust the input-output delay, observe the reference and feedback waveforms in the Digital Oscilloscope and increase the delay until they are aligned visually, as shown below:



9. **Stop the Random Function Generator.** Press the **Stop** button to bring the system to rest.

10. **Adjust the reset integrator.** Ideally the controller output signal is zero when the system is at rest. This may not be the case if there is a static offset somewhere in the system. To remove a static offset, increase the reset integrator gain and observe the rate at which the controller output signal is driven to zero. More reset gain will result in faster offset removal. Values in the range of 0.1 to 1.0 are typical.

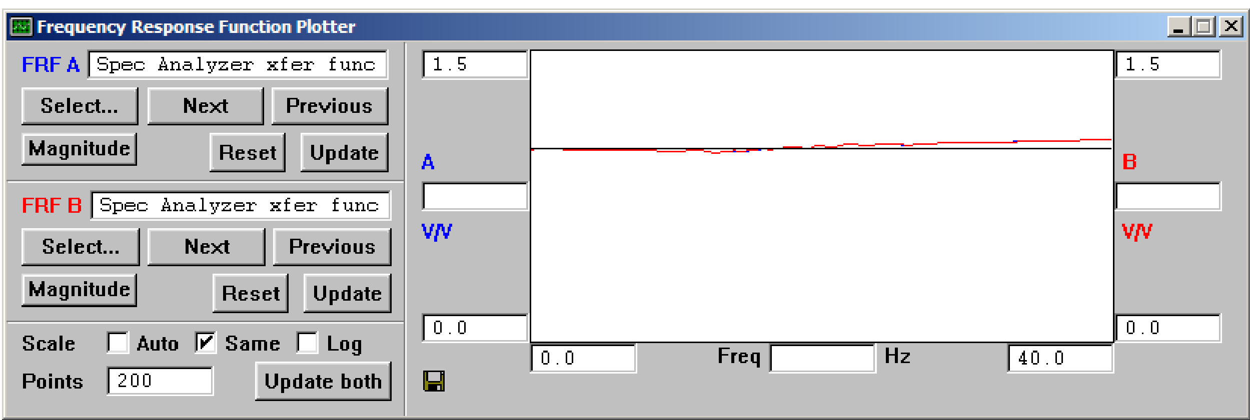
    If you observe that Reset Integrator Tracking indicator is glowing red, that means that the correction that reset integrator needs to apply to remove the offset is beyond the its authority limit. Increase the Reset Integrator Maximum Authority slider bar in small increments until the indicator glows green. If the indicator is still red after having increased the authority a reasonable amount, it could be that there is a problem with the electrical or mechanical system that you should diagnose before continuing.

Velocity Control Tuning

1. **Set up the Reference Generator.** Set the cut-in frequency to the lowest anticipated velocity reference frequency, keeping in mind the physical displacement limits. Set the cutoff frequency to the maximum allowable value.

2. **Set up the Random Function Generator.** Set the shape to "1/F", the minimum frequency to match the cut-in frequency of the Reference Generator, and the maximum frequency according to the desired control bandwidth.

3. **Complete the steps outlined in the following section on Acceleration Control Tuning, starting with Step 3.** Velocity control tuning is done much like acceleration control tuning except for the setup of the Reference Generator and the Random Function Generator. When completed, the frequency response looks like this:

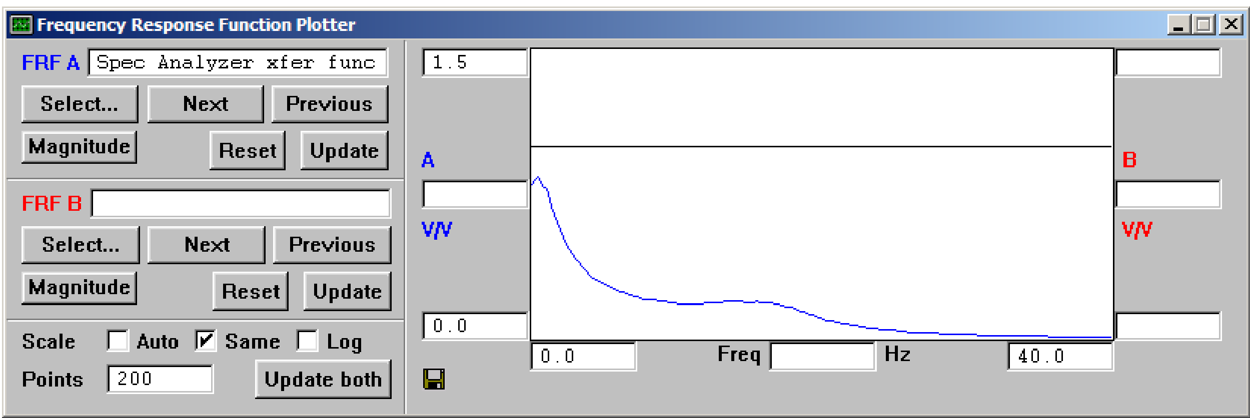


Acceleration Control Tuning

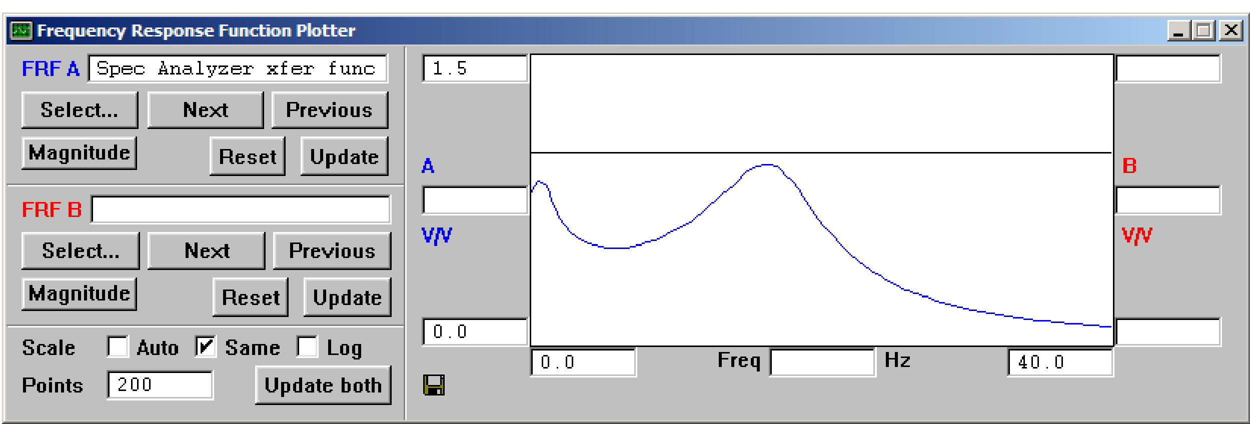
1. **Set up the Reference Generator.** Set the cut-in frequency to the lowest anticipated acceleration reference frequency, keeping in mind the physical displacement limits. Note that the cut-off frequency cannot be adjusted because it has no effect in acceleration control mode.

2. **Set up the Random Function Generator.** Set the shape to "Flat", the minimum frequency to match the cut-in frequency of the Reference Generator, and the maximum frequency according to the desired control bandwidth.

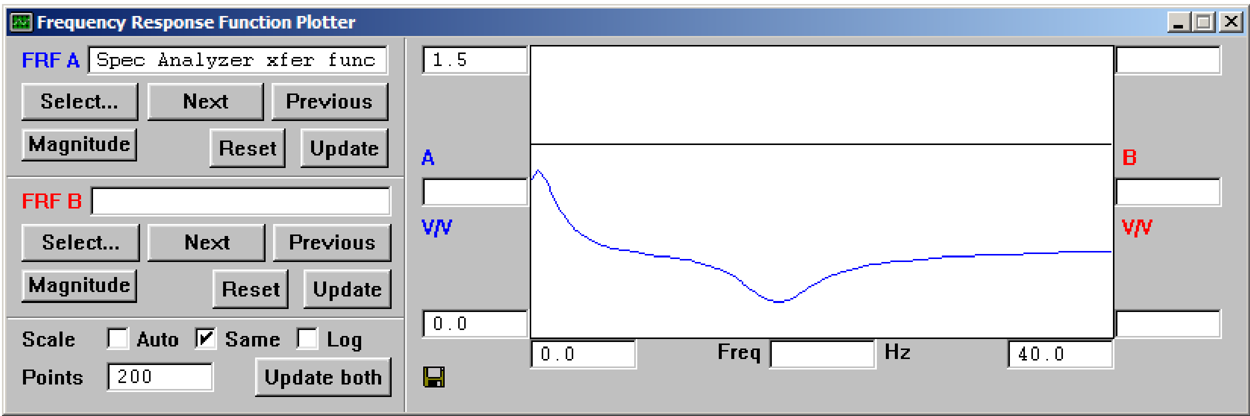
3. **Perform basic displacement control tuning.** Do Steps 3 through 6 described in the Displacement Control Tuning section, after which the frequency response should look like this:



4. **Increase the velocity lead.** Increase the velocity lead to boost the frequency response below the oil column natural frequency. This will also boost the response at the oil column natural frequency, but don't be concerned about it at this point. The frequency response then should look like this:

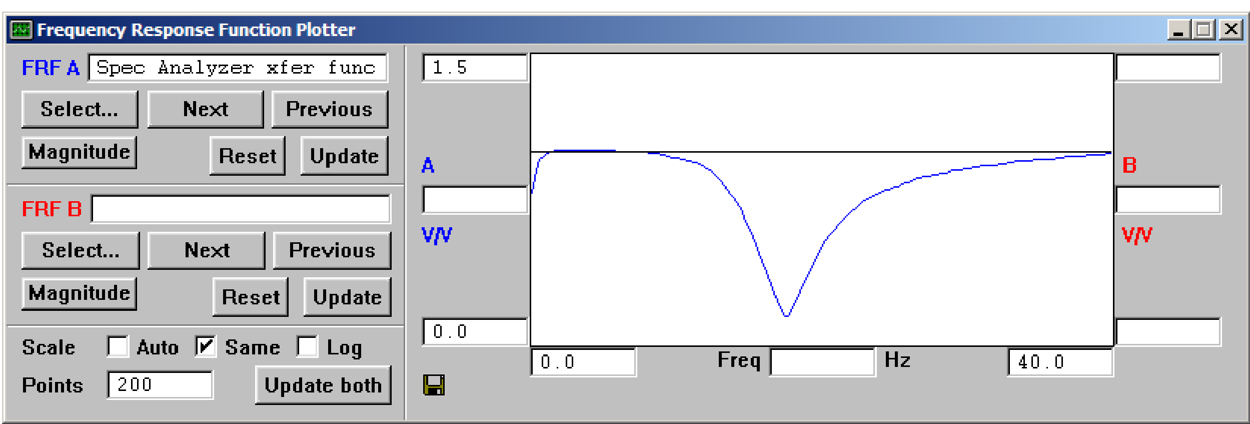


5. **Increase the jerk lead.** Increase the jerk lead to boost the frequency response above the oil column natural frequency. This may cause the peaking response at the oil column natural frequency observed in the previous step to be reduced due phase cancellation. Add only enough jerk lead so that the frequency response is flat overall, as shown below:

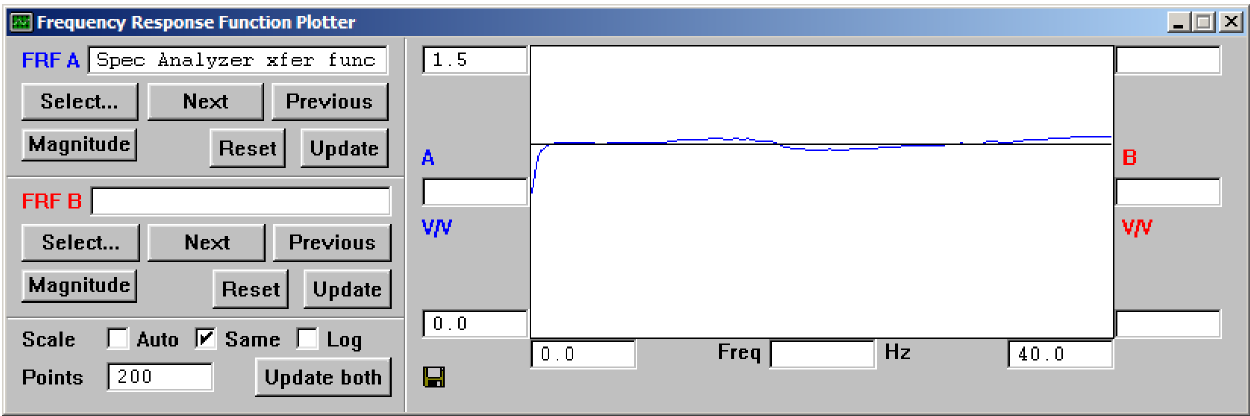


6. **Continue boosting response below and above the oil column natural frequency.** Repeat the previous two steps, increasing velocity lead and jerk lead in small increments. Do not use large increments or else the effect of one lead will wash over into the other lead's frequency region, causing peaks or valleys in the frequency response that make it hard to determine which lead to adjust. In other words, make sure the overall response is reasonably flat at a given level (except near the oil column natural frequency) before boosting it to the next level.

   When you have finished boosting the frequency response either side of the oil column natural frequency to unity, it should look like this:



7. **Increase the acceleration lead.** Increase the acceleration lead to boost the response near the oil column natural frequency to unity. You may have to make slight adjustments to velocity and jerk leads to keep the response below and above the oil column natural frequency at unity. The frequency response should then look like this:

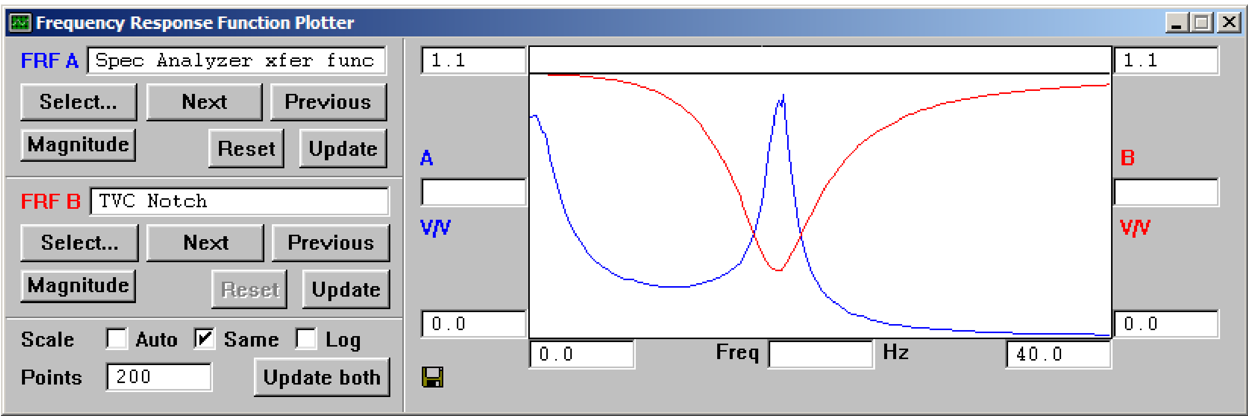


8. **Adjust the input-output delay and the Reset Integrator.** Do Steps 8 through 10 described in the Displacement Control Tuning section.

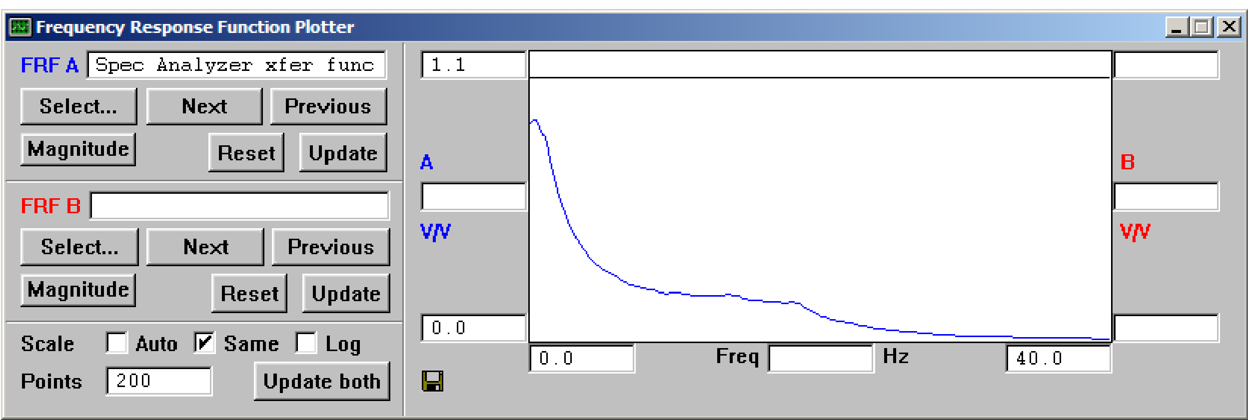
Suppressing Oil Column Resonance Using a Notch Filter

Force feedback is the preferred method of suppressing the oil column resonance because it tracks changes in oil column natural frequency with temperature and actuator displacement. However, if a force sensor is not available, a notch filter can be used instead with similar results.

In the figure below, the frequency response (Channel A (blue)) shows a large peak at the oil column natural frequency. Channel B (red) shows the frequency response of the notch filter that will be applied to eliminate the resonant peak.



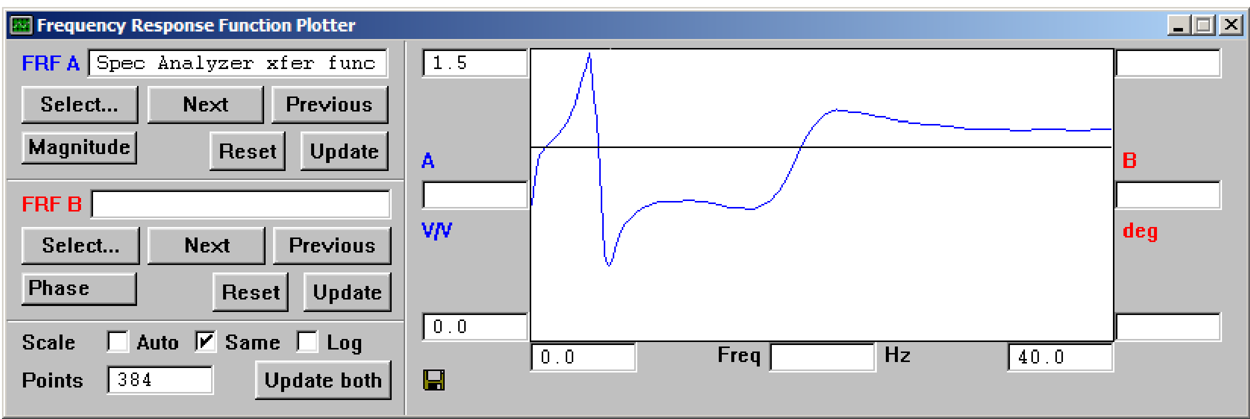
With the notch filter applied, the oil column resonance has been completely suppressed:



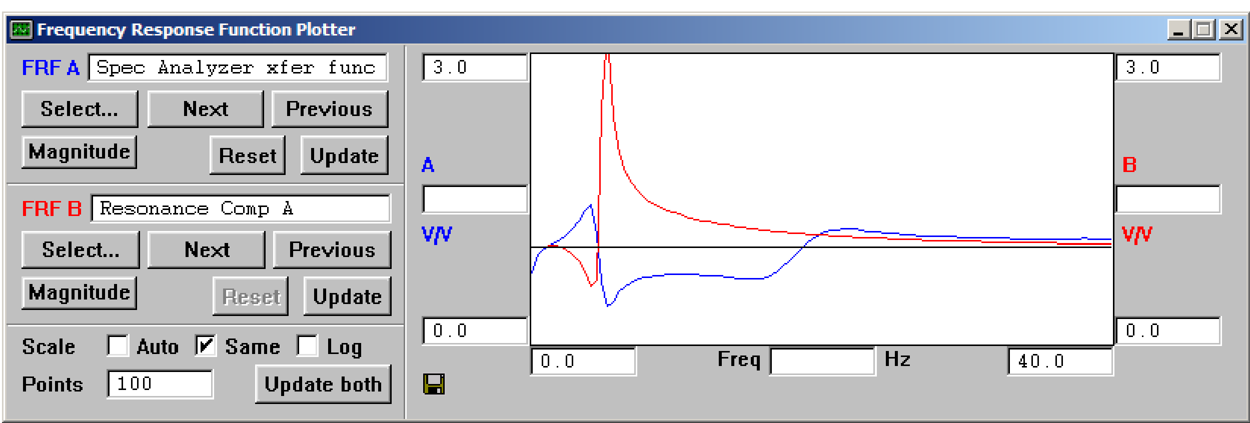
Compensating Payload Resonances Using Notch Filters

The tuning procedures presented so far assume that the payload is a rigid mass. If instead the payload has resonant modes, the task of tuning becomes more complex. Resonances and antiresonances cause sharp peaks in the frequency response. To deal with these, the notch filters of the Resonance Compensator are employed.

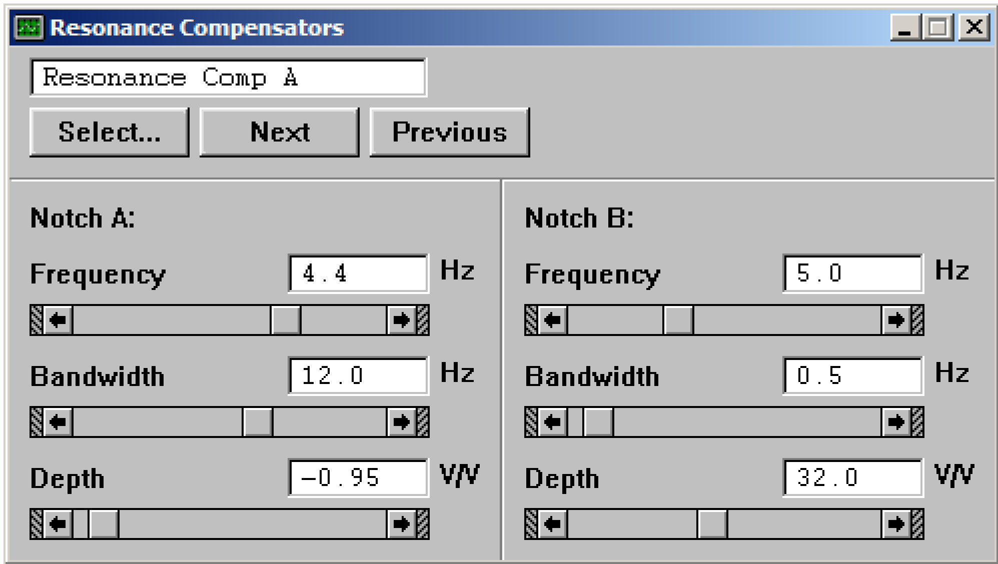
In the following example, a bare seismic table is tuned using the tuning procedures previously discussed. Then a heavy, lightly damped 5 Hz resonant specimen is placed on the table, but the tuning is left unchanged. The resulting frequency response then looks like this:



There is a resonance at 4 Hz followed by a sharp transition to an antiresonance at 5.4 Hz. Using the Resonance Compensator Panel, a notch is placed on top of the resonance and an antinotch on top of the antiresonance, as shown in Channel B (red) below:

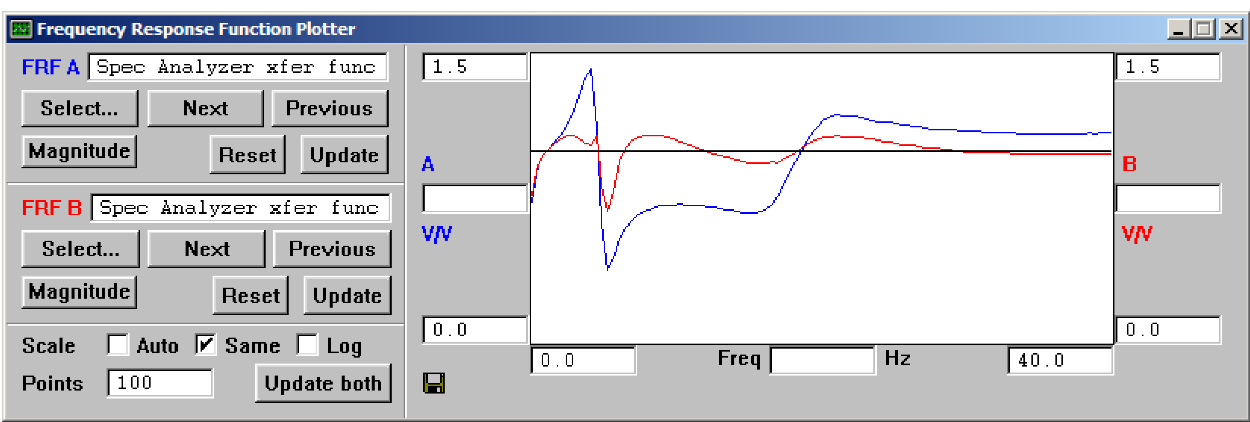


The Resonance Compensator notch filter parameters that achieve this composite notch frequency response are as follows:



Note that the center frequencies of the notch and antinotch are slightly offset from the measured resonance and antiresonance frequencies; this is almost always the case, so remember to always offset the notch frequencies a little bit for best results.

With the notch and antinotch filters as above, the system frequency response is that shown in Channel B (red) below superimposed on the original frequency response in Channel A (blue):



The frequency response is far from perfect, but it is still considerably improved.

While tuning the Resonance Compensator notches, you may have to adjust the TVC gains a little. In the above example, the jerk lead was reduced by 13% to reduce peaking caused by the large gain of the antinotch.

Switching Control Modes With Hydraulics On

Most operators like to warm up the system in displacement control, then switch to acceleration control to run the test. Contrary to expectation, switching the control mode is not simply a matter of pressing the Control Mode radio button in the TVC Panel. There are many controller parameters that depend on the control mode and so must be modified to values appropriate for the new mode. Because of the large number of modifications required and the ease of forgetting one, the recommended way of changing modes is to have different settings files for different modes. Before a settings file can be downloaded, the hydraulic power must be turned off because the downloading of new calibration, gains, etc. can cause large controller transients. However, cycling hydraulic power can be very inconvenient and time consuming in some systems, especially if accumulators have to be discharged and recharged. In such systems, it would be convenient start up the system with an acceleration settings file, then change only a minimum necessary number of parameters to allow warmup in displacement mode, then change back to acceleration mode, with hydraulics on throughout.

To change from acceleration (or velocity) to displacement control for system warmup purposes, first press the **Save Reference Gains** button to save currently active gain values, and then set all the lead gains to zero. You can now warm up the system with a low frequency sine wave. If you are using any notch filters, you must make sure that the sine wave frequency is well below all notch center frequencies or else large motions may result.

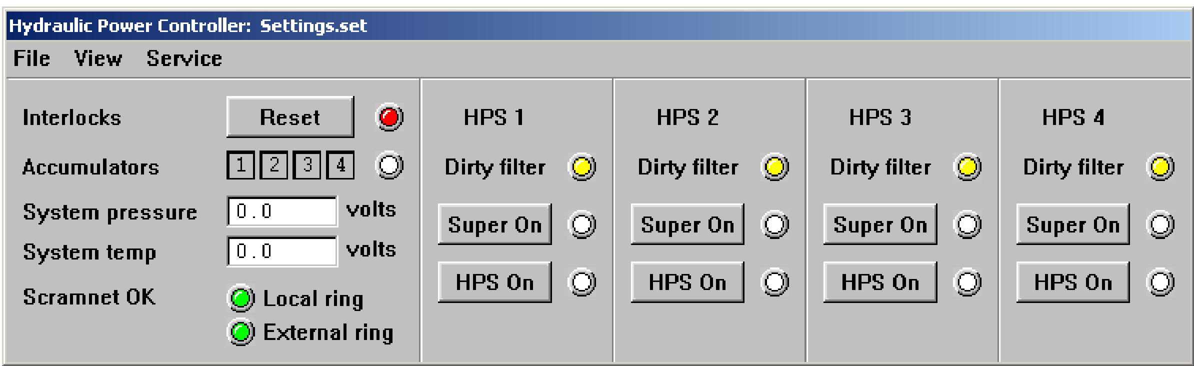
When you are finished with system warmup, switch back to acceleration (or velocity) control and then restore the lead gains by pressing the **Restore Reference Gains**.

Section 9

Hydraulic Power Controller Reference

Introduction

The Hydraulic Power Controller is a centralized control unit used to control the four pumps and four accumulators. The operator can operate these systems using the following panel.



This section describes this panel.

Panel Description

System controls on the main panel allow you to perform the following tasks:

- Reset limit/interlock conditions
- Enables desired accumulator banks
- Monitor system pressure and temperature
- Monitor the HPS's
- Monitor scramnet

The following menus are provided:

- **File**—allows you to change passwords for access privileges, restore or save settings, and quit the application
- **View**—allows you to read the message log

Hydraulic Power Controller (continued)

Access

The main panel opens when you start the application. It cannot be closed except by quitting the application.

When to Use the Panel

Use this panel to monitor the hydraulic control system.

Control Descriptions

Control	Description
Interlocks Reset button and status indicator	Use the **Interlocks Reset** button to clear the hardware and software limit status indicators located on the Conditioners and Limit Detector panels and the system E-STOP chain. The indicator will be red when an interlock has occurred.
Accumulators 1-4 buttons and status indicator	Enables the desired accumulator stands for high flow tests.. The status indicator will turn green when the accumulators are pressurized.
System pressure display box	Displays the system oil pressure.
System temp display box	Displays the system oil temp.
Scramnet OK indicators	When the appropriate light is green, indicates that Scramnet for that ring is connected and functioning properly: Local ring – along with the MTS HP controller; includes the MTS Table 1 controller, MTS Table 2 controller, and the MTS Structural controller. External ring – along with MTS HP controller, includes customer external connections
HPS 1 -4	
Dirty Filter indicator	Indicates when the filter is dirty.
Super On button and indicator	Non-functioning.
HPS On button and indicator	When pressed, turns the HPS On. The light will turn green when the pumps reach the system operating pressure.

Appendix A

Scramnet

Scramnet Signals

The following is a list of signals, their Scramnet memory source, and each corresponding source.

Notes:

1. The first 1024 words of scramnet memory are reserved for MTS use.
2. All signals are single precision floating point (32 bits) unless otherwise noted.
3. Signals designated as integer are 32 bits.

Scramnet Memory Location	Source	Description
0	XPC	Master span
1	XPC	STS Act 1 Ctl mode (int32)
2	XPC	STS Act 2 Ctl mode (int32)
3	XPC	STS Act 3 Ctl mode (int32)
4	XPC	STS Act 4 Ctl mode (int32)
5	XPC	STS Act 5 Ctl mode (int32)
6	XPC	STS Act 1 Displ cmd
7	XPC	STS Act 2 Displ cmd
8	XPC	STS Act 3 Displ cmd
9	XPC	STS Act 4 Displ cmd
10	XPC	STS Act 5 Displ cmd
11	XPC	STS Act 1 Force cmd
12	XPC	STS Act 2 Force cmd
13	XPC	STS Act 3 Force cmd
14	XPC	STS Act 4 Force cmd
15	XPC	STS Act 5 Force cmd
16	XPC*	STS Act 1 Displ fbk

Scramnet Memory Location	Source	Description
17	XPC*	STS Act 2 Displ fbk
18	XPC*	STS Act 3 Displ fbk
19	XPC*	STS Act 4 Displ fbk
20	XPC*	STS Act 5 Displ fbk
21	XPC*	STS Act 1 Force fbk
22	XPC*	STS Act 2 Force fbk
23	XPC*	STS Act 3 Force fbk
24	XPC*	STS Act 4 Force fbk
25	XPC*	STS Act 5 Force fbk
26	XPC*	STS Act 1 DP Force fbk
27	XPC*	STS Act 2 DP Force fbk
28	XPC*	STS Act 3 DP Force fbk
29	XPC*	STS Act 4 DP Force fbk
30	XPC*	STS Act 5 DP Force fbk
31	XPC*	STS User DUC #1
32	XPC*	STS User DUC #2
33	XPC*	STS User DUC #3
34	XPC*	STS User DUC #4
35	XPC*	STS User DUC #5
36	XPC*	STS User DUC #6
37	XPC	STS Digital output #1 (int32)
38	XPC	STS Digital output #2 (int32)
39	XPC	STS Digital output #3 (int32)
40	XPC	STS Digital output #4 (int32)
41	XPC	TBL1 Long Reference
42	XPC	TBL1 Lat Reference
43	XPC	TBL1 Vert Reference
44	XPC	TBL1 Roll Reference
45	XPC	TBL1 Pitch Reference

SCRAMNET MEMORY LOCATION	SOURCE	DESCRIPTION
46	XPC	TBL1 Yaw Reference
47	XPC	TBL2 Long Reference
48	XPC	TBL2 Lat Reference
49	XPC	TBL2 Vert Reference
50	XPC	TBL2 Roll Reference
51	XPC	TBL2 Pitch Reference
52	XPC	TBL2 Yaw Reference

(*written by XPC in realtime simulation mode)

SCRAMNET MEMORY LOCATION	SOURCE	DESCRIPTION
53	STS	Master span
54	STS	Act 1 Ctl mode (int32)
55	STS	Act 2 Ctl mode (int32)
56	STS	Act 3 Ctl mode (int32)
57	STS	Act 4 Ctl mode (int32)
58	STS	Act 5 Ctl mode (int32)
59	STS	Act 1 Displ cmd
60	STS	Act 2 Displ cmd
61	STS	Act 3 Displ cmd
62	STS	Act 4 Displ cmd
63	STS	Act 5 Displ cmd
64	STS	Act 1 Force cmd
65	STS	Act 2 Force cmd
66	STS	Act 3 Force cmd
67	STS	Act 4 Force cmd
68	STS	Act 5 Force cmd
69	STS	Act 1 Displ fbk
70	STS	Act 2 Displ fbk

Scramnet Memory Location	Source	Description
71	STS	Act 3 Displ fbk
72	STS	Act 4 Displ fbk
73	STS	Act 5 Displ fbk
74	STS	Act 1 Force fbk
75	STS	Act 2 Force fbk
76	STS	Act 3 Force fbk
77	STS	Act 4 Force fbk
78	STS	Act 5 Force fbk
79	STS	Act 1 DP Force fbk
80	STS	Act 2 DP Force fbk
81	STS	Act 3 DP Force fbk
82	STS	Act 4 DP Force fbk
83	STS	Act 5 DP Force fbk
84	STS	Act 1 Valve out
85	STS	Act 2 Valve out
86	STS	Act 3 Valve out
87	STS	Act 4 Valve out
88	STS	Act 5 Valve out
89	STS	User DUC #1
90	STS	User DUC #2
91	STS	User DUC #3
92	STS	User DUC #4
93	STS	User DUC #5
94	STS	User DUC #6 write generates XPC interrupt
95	STS	Digital input #1 (int32)
96	STS	Digital input #2 (int32)
97	STS	Digital input #3 (int32)
98	STS	Digital input #4 (int32)

Scramnet Memory Location	Source	Description
99	TBL1	Master span
100	TBL1	Long Reference
101	TBL1	Lat Reference
102	TBL1	Vert Reference
103	TBL1	Roll Reference
104	TBL1	Pitch Reference
105	TBL1	Yaw Reference
106	TBL1	TBL2 Long Reference
107	TBL1	TBL2 Lat Reference
108	TBL1	TBL2 Vert Reference
109	TBL1	TBL2 Roll Reference
110	TBL1	TBL2 Pitch Reference
111	TBL1	TBL2 Yaw Reference
112	TBL1	TBL2 Long Frequency
113	TBL1	TBL2 Lat Frequency
114	TBL1	TBL2 Vert Frequency
115	TBL1	TBL2 Roll Frequency
116	TBL1	TBL2 Pitch Frequency
117	TBL1	TBL2 Yaw Frequency
118	TBL1	Long Displacement fbk
119	TBL1	Lat Displacement fbk
120	TBL1	Vert Displacement fbk
121	TBL1	Roll Displacement fbk
122	TBL1	Pitch Displacement fbk
123	TBL1	Yaw Displacement fbk
124	TBL1	Long Velocity fbk
125	TBL1	Lat Velocity fbk
126	TBL1	Vert Velocity fbk
127	TBL1	Roll Velocity fbk

SCRAMNET MEMORY LOCATION	SOURCE	DESCRIPTION
128	TBL1	Pitch Velocity fbk
129	TBL1	Yaw Velocity fbk
130	TBL1	Long Acceleration fbk
131	TBL1	Lat Acceleration fbk
132	TBL1	Vert Acceleration fbk
133	TBL1	Roll Acceleration fbk
134	TBL1	Pitch Acceleration fbk
135	TBL1	Yaw Acceleration fbk
136	TBL1	Long Force fbk
137	TBL1	Lat Force fbk
138	TBL1	Vert Force fbk
139	TBL1	Roll Force fbk
140	TBL1	Pitch Force fbk
141	TBL1	Yaw Force fbk

Scramnet Memory Location	Source	Description
142	TBL2	Master span
143	TBL2	Long Reference
144	TBL2	Lat Reference
145	TBL2	Vert Reference
146	TBL2	Roll Reference
147	TBL2	Pitch Reference
148	TBL2	Yaw Reference
149	TBL2	TBL1 Long Reference
150	TBL2	TBL1 Lat Reference
151	TBL2	TBL1 Vert Reference
152	TBL2	TBL1 Roll Reference
153	TBL2	TBL1 Pitch Reference
154	TBL2	TBL1 Yaw Reference
155	TBL2	TBL1 Long Frequency
156	TBL2	TBL1 Lat Frequency
157	TBL2	TBL1 Vert Frequency
158	TBL2	TBL1 Roll Frequency
159	TBL2	TBL1 Pitch Frequency
160	TBL2	TBL1 Yaw Frequency
161	TBL2	Long Displacement fbk
162	TBL2	Lat Displacement fbk
163	TBL2	Vert Displacement fbk
164	TBL2	Roll Displacement fbk
165	TBL2	Pitch Displacement fbk
166	TBL2	Yaw Displacement fbk
167	TBL2	Long Velocity fbk
168	TBL2	Lat Velocity fbk
169	TBL2	Vert Velocity fbk
170	TBL2	Roll Velocity fbk

SCRAMNET MEMORY LOCATION	SOURCE	DESCRIPTION
171	TBL2	Pitch Velocity fbk
172	TBL2	Yaw Velocity fbk
173	TBL2	Long Acceleration fbk
174	TBL2	Lat Acceleration fbk
175	TBL2	Vert Acceleration fbk
176	TBL2	Roll Acceleration fbk
177	TBL2	Pitch Acceleration fbk
178	TBL2	Yaw Acceleration fbk
179	TBL2	Long Force fbk
180	TBL2	Lat Force fbk
181	TBL2	Vert Force fbk
182	TBL2	Roll Force fbk
183	TBL2	Pitch Force fbk
184	TBL2	Yaw Force fbk

SCRAMNET PARAMETERS

Local scramnet ring node numbers:

TBL1	1
TBL2	2
STS	3
HPC	4

External scramnet ring node numbers:

HPC	1

Max number of scramnet nodes: 10

Control register values

CSR	VALUE
0	0x8103
1	0x8000
2	0xC040
3	0x0100
4	0x5554
5	0x0055
6	0x8103
7	0x0000
8	0xB881
9	0x0029
10	0x0001
11	0x0000
12	0x0000
13	0x0131
14	0x3F80
15	0x0000