- **Rear Door Configuration** – A new rear door on the Tower Console replaces the old Frame Interface Box. The Tower Rear Door is now the central connection point for interconnecting the units of the system.
- **Waveform Generator Frequency** – The Waveform Generator frequency limit has been increased from 100 Hz to 500 Hz. This is a direct result of the faster sampling rate.

Throughout the instruction manuals, all references to the Model 8500 are actually references to the Model 8500 PLUS, unless otherwise stated.

This manual is also applicable to Model 8562 Dynamic Testing Systems. Model 8562 systems utilize an electromechanical actuator rather than a servohydraulic actuator. The advantage of this is that the Model 8562 does not require a hydraulic subsystem and its associated cooling requirements, but it does give up some dynamic capability in the process. From an operational viewpoint, the Model 8500 and the Model 8562 are nearly identical, share most of the same components, and, except where hydraulic operations are concerned, operate in identical fashion. Thus, you can use this manual for either type of system.

Model 8500 - What It Is And What It Does

The Model 8500 and Model 8560 Testing Systems are closed-loop testing systems which apply static or dynamically changing forces to materials and test them into a failure condition. Model 8500 Dynamic Testing Systems are powered by hydraulics, and can create forces up to 2.5MN (560,000 lbf) or more at frequencies from 0 to 500 Hz or higher, depending on the force level. A typical Model 8500 System is shown in the frontispiece, and consists of a closed load frame with a movable crosshead, a hydraulic actuator to apply a force, gripping mechanisms to hold the mechanical test specimen, and a load cell to measure the force. The position of the actuator piston is measured by a displacement transducer, and a variety of extensometers are available which measure the mechanical strain on the specimen. Load, position and strain are the basic parameters needed by a user of the system.

In all Servohydraulic Systems, the actuator piston is under closed loop control by controlling the hydraulic fluid flowing through a servovalve supplying the actuator. Of basic interest in a mechanical test is the control mode, which is the independent variable in the loop control. In some tests, the user may wish to control displacement of the specimen and measure resulting load and strain; in others, it may be that known forces or strains are to be applied and the corresponding dependent parameters measured. Frequently, it is required to move instantaneously from control under one parameter to control under another - this is called mode transfer, and the smoothness of this transition is one measure of the quality of the system.

The discussions in this manual apply equally to the electric actuator-based systems of the Instron Model 8560. While most of the material presented is concerned with hydraulic systems, closed-loop servo control is also possible with the electric actuator, and the circuits and functions are essentially identical for both types of systems.

Analog versus Digital Control

The development of direct digital controllers for closed loop control of dynamic mechanical testing systems resulted from the availability of high performance digital signal processors, originally aimed at the consumer electronics market. This offered a low-cost opportunity to change the control loop from conventional analog to purely digital. A distributed microprocessor architecture with a unique token-passing scheme was developed, which led to a number of significant new benefits.

Analog Testing Systems

For many years, dynamic testing systems were strictly analog instruments. Command, control, feedback, and readout signals were all analog, and measurement of what was happening in the system could be obtained directly using standard test equipment.

A typical example of the old-style analog control loop is shown in the block diagram in Figure 1-1. It shows the basic elements of all servocontrol loops, and we'll use it here to demonstrate the differences between analog and digital control. A mean level generator and a cyclic function generator are summed to provide a composite command signal, which is then compared with the controlling feedback signal. The resulting error signal, after loop shaping to improve dynamic performance, is applied to the servovalve controlling the actuator. The parameters of the loop are all analog voltages, which are manually set by control potentiometers or by digital/analog converters from a digital keyboard input. Changing the control mode requires the error to be close to zero in

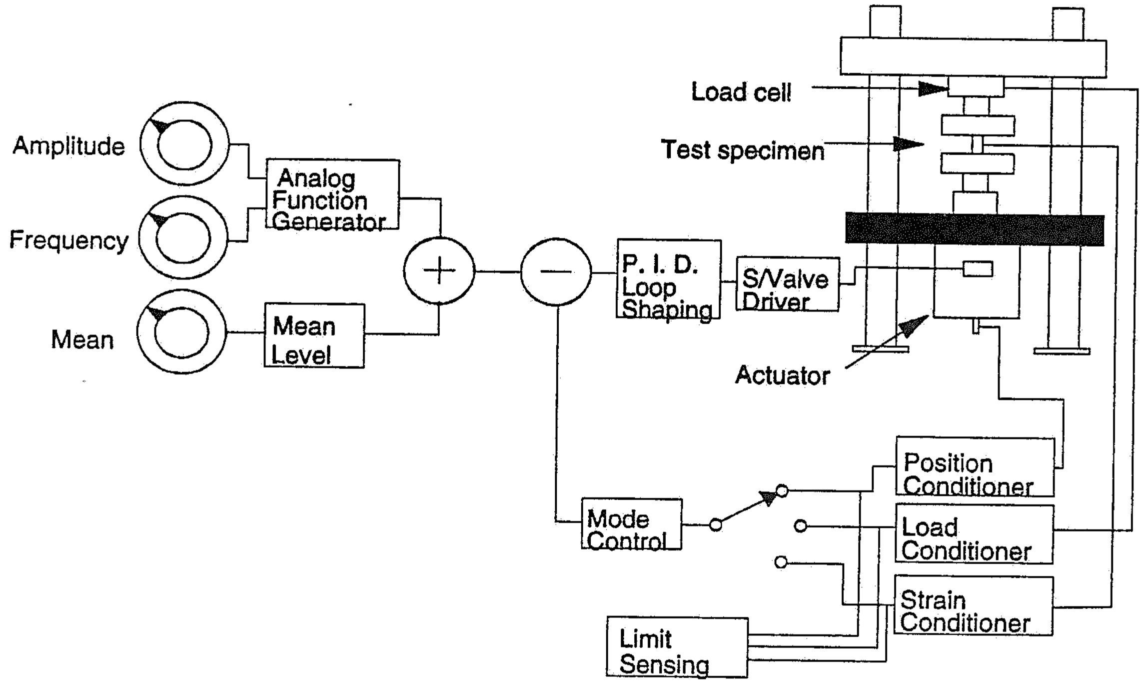


Figure 1-1. Typical Analog Testing System

the new target mode of control before transfer occurs, and can require complex circuitry.

The next generation of testing systems used a hybrid control, replacing the manual controls of the analog system with multiple digital/analog controls under the command of a computer, but the control loop remained essentially an analog loop.

Digital Testing Systems

In the Model 8500, the analog control loop is replaced with a totally digital loop. Since most available transducers are analog devices, and the controlling servovalve is analog, we still have to have analog processing at the peripheries of the control loop. However, the difference between a digital and an analog loop is that the summing junction for command and feedback is digital rather than analog. A block diagram of the digital control loop is shown in Figure 1-2. The command generation is now a totally digital process - the composite command is simply a sequence of numerical values at the basic loop update rate. Each of the transducer sensor conditioners supplies a stream of feedback values at the same update rate, and one of these streams, determined by the current control mode, is compared with the com-

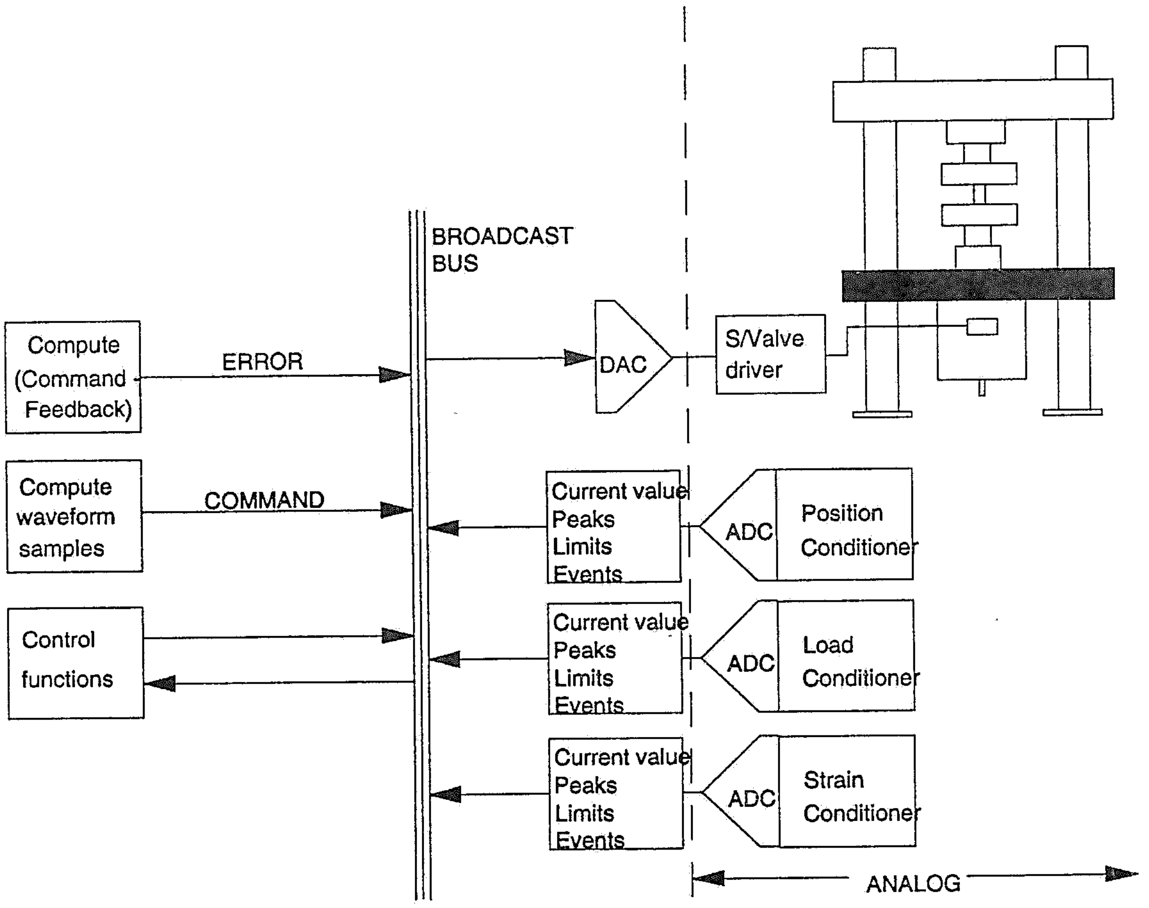


Figure 1-2. Digital Control Loop Block Diagram

mand by digital subtraction, and hence, a stream of error values is generated. This digital stream is applied to a digital-to-analog converter to drive the servovalve.

From the beginning, the benefits of digital control were obvious to the development team:

- control mode transfers are simple, because, in a digital system, you can always ensure absolutely that the command can be set equal to the current feedback when you wish to change control modes,
- digital components are consistently being reduced in cost for a given performance,
- digital systems are more easily manufactured, since there are none of the offset and gain adjustments required by analog systems.

About This Manual

The foregoing is a very brief description of the all-digital Model 8500 System. It is an introduction to a greater level of detail about the Model 8500 that some users may want or need when operating the Model 8500. This Reference Manual is part of the overall manual set that includes the Operating, Installation and Maintenance, Load Frame, Computer Interface, and Hydraulic Power Supply Instruction Manuals, along with manuals for optional accessories.

This Reference Manual is intended to give you more in-depth detail about the design and features of the Model 8500 System than is available in the other manuals. If we were to include even some of the information contained in this manual in the Operating Instructions, the Operating Instructions manual would become very large and cumbersome, making it very difficult to use while operating the system. Thus, the Operating Instructions manual contains only enough information about a feature or function to enable you to use it. If you need to know more about a particular subject, look it up in this Reference Manual.

Chapter 2 is a description of the Model 8500 hardware, including a description of the System Block Diagram, the Tower Console, the Master Dynamic Controller Board, and the Sensor Conditioner Cards. This information will be helpful in understanding how the system works, and provides the framework for the chapters that follow.

Chapter 3 shows how the system Composite Command Waveform is derived and used. It describes the various command waveforms: how they are generated, how their parameters are set, and the accuracy and resolution of each. It also describes how external waveforms are handled, and includes a description of Constant Amplitude Control.

Chapter 4 covers Feedback Waveform Processing. It includes sections on transducer recognition, the calibration process, Auto-Ranging, Zero Suppression, and Peak Detection.

Chapter 5 is a discussion of Servo Loop Control and how Loop Shaping can be used to optimize the performance of the system.

Chapter 6 is a description of Adaptive Control and how it is used to automatically adjust loop parameters for changes in specimen stiffness during a materials test.

Chapter 7 is an extensive discussion of Event Detectors. It describes the difference between Limits and Event Detectors, and goes on to describe the Safety Limits and Event Detectors in great detail, including their characteristics, setup, and various operating states.

Chapter 8 describes how User States are saved and restored, and includes information on the storage of test setups and calibration values, and how to retrieve them.

Chapter 9 is hardware related - it describes the system Hydraulic Control Manifold, its uses, its role in the Docile Mode, and how it relates to the servovalve. This chapter also contains information on the Analog Output Jacks and hints on swapping Tower cards, should this task become necessary.

Chapter 10 discusses Multi-Axial systems. When there is more than one actuator in a system (as in structures testing systems or biaxial component testing systems), the separate channels must be synchronized to operate smoothly together. This chapter gives information on Master-Slave channel relationships, and information on cross-compensation between channels.

In the Appendices of the manual, you will find instructions for selecting transducer recognition and calibration resistors, an example of the use of Event Detectors, and an example of how Auto-Ranging can increase system resolution. Finally, there is a Glossary of terms used in Materials Testing. Included in the Glossary are a number of topics that are unique to the Model 8500 that may be unfamiliar to some users of the system, or whose meaning may have changed with the changeover to an all-digital system.

Chapter 2
Functional Description

Outline

- Introduction .... Page 2-2
- System Component Interactions .... Page 2-3
- Tower Console .... Page 2-7
- Master Dynamic Controller Card .... Page 2-12
- Sensor Conditioner Cards .... Page 2-14

This chapter is a description of the Model 8500 System hardware; its units, subassemblies, and components. It is intended to give you a reasonably detailed picture of the different parts of the system, how they work, and how they interact with each other. With this information, you will be better equipped to understand the information presented later in the manual.

Introduction

Each of the following sections is based upon a functional block diagram. The diagrams are presented in pull-out form.

The functional block diagrams described in the next four sections are given in hierarchical order; that is, the system block is shown first, and then the blocks that make up the system block are given. In this way, you should gain a better understanding of how the system fits together.

System Component Interactions

The System Functional Block Diagram, shown in Figure 2-1, gives an overall picture of how the system components relate to each other. The most important component in the diagram is the Tower Console which is the “brain” of the system, and is involved in nearly all of the system functions.

Your interface with the system is via the Front Panel Console. Commands are entered at the Front Panel to set up the system, to calibrate the transducers and to carry out the required test. The control signals generated from the Front Panel interface directly with the Master Dynamic Controller in the Tower Console. The Master Controller generates a digital command waveform signal of the form, amplitude and frequency as set up on the Front Panel.

The Master Controller also monitors the output from the Sensor Conditioner cards. Each card is connected to a particular transducer, which measures either the load or strain experienced by the specimen, or the position of the load frame actuator. Feedback signals from the transducers, which result from the response of the specimen to the command signals, are received and digitized by the cards.

The Master Controller compares the transducer signals to the command signals and, if an error is found between them, a signal is generated to drive the actuator in the direction and by the amount necessary to reduce the error to zero, thus forming a closed-loop servo system.

The Tower Rear Door is a connector panel that acts as the electrical interface between the Tower Console, the Load Frame, the Front Panel Console, and the hydraulic power supply. The door also contains pre-amplifier circuit boards to provide amplification of the transducer signals before they are applied to the Sensor Conditioner cards.

There are also several provisions for the connection of external transducers and other analog devices on the rear door. The digital input/output lines carry signals for turning on and off external digital devices such as alarms, while the high level analog inputs carry command and feedback signals to external analog devices such as an analog function generator.

There are switched output lines for monitoring command and feedback signals for the A and B channels of an oscilloscope and the X and Y channels of a recorder. In addition, there are unswitched analog outputs which provide all the analog outputs on a single connector.

Finally, there is a provision for completely automated computer control of the system through the IEEE-488 GPIB Bus, which allows an optional computer to be connected to the system. Application programs written for specific materials tests can be run on the computer, which affords not only command and control of the system, but resulting data reduction, as well. A complete description of the Command Set for this option is given in the GPIB Interface manual.

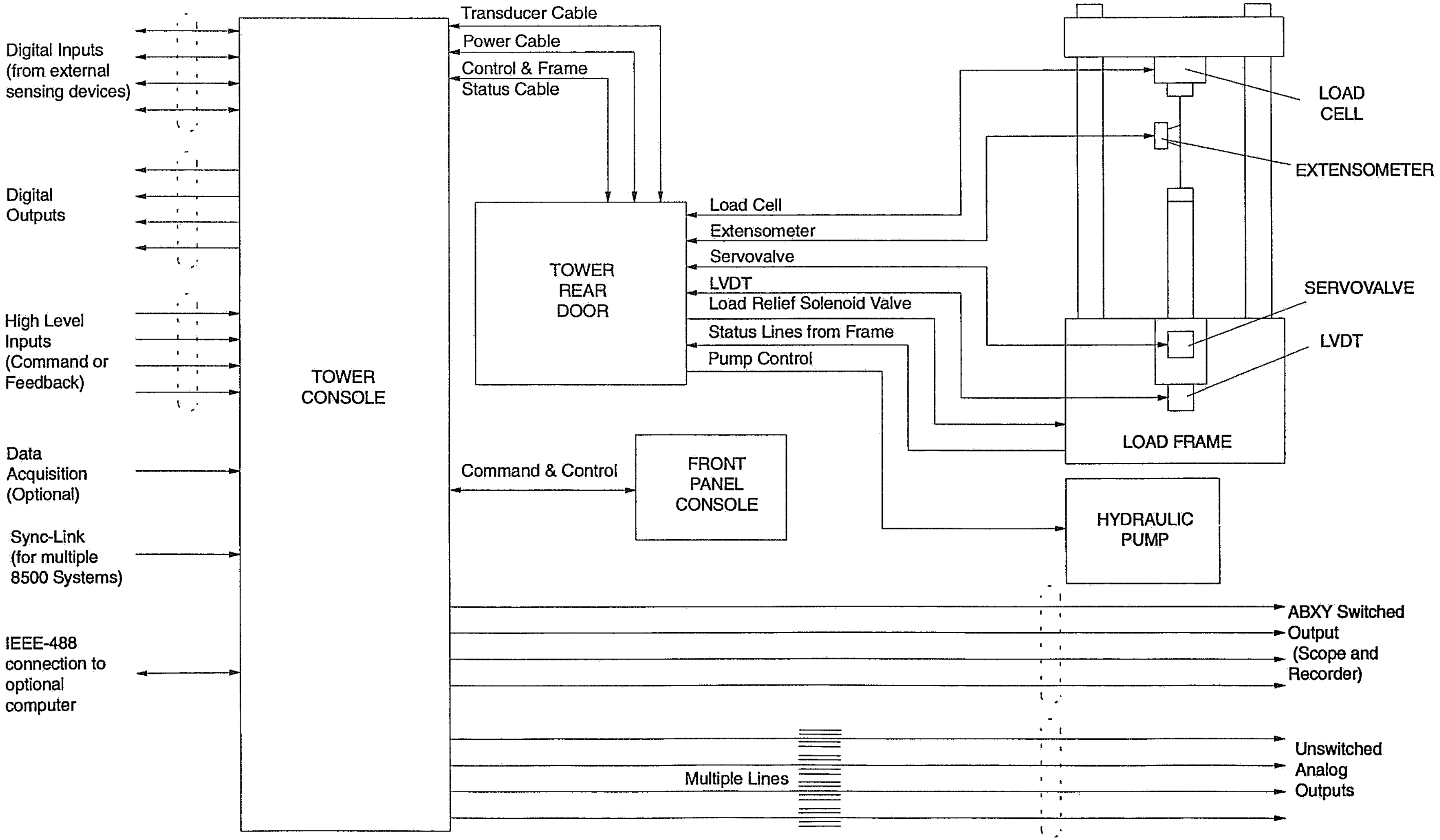


Figure 2–1. System Functional Block Diagram

Tower Console

If the key to the Model 8500 System is the Tower Console, then the key to the Tower itself is the backplane bus. The backplane bus provides the interconnecting link for the Master Controller card, the Sensor Conditioner cards and, where used, the Data Acquisition card. Signals, power, and tokens are passed to all six cards simultaneously. A functional block diagram of the Tower Console is shown in Figure 2-2.

All signals entering and leaving the Tower Console do so through connectors on the rear panel. For purposes of simplicity and clarity, the rear panel is shown in two sections; the one on the left carries all the input signals, while the one on the right carries the output signals.

Inputs from low level transducers, such as load cells and extensometers, are passed through a preamplifier on the Tower rear door. High level analog inputs, already conditioned to ten volts full-scale, are connected directly to the rear panel.

The processing of high level and low level transducer signals is performed by the individual Sensor Conditioner cards and the periodic digitized results are placed on the backplane bus that connects all cards in the Tower.

One of the many functions of the Master Dynamic Controller board is Command Generation. Set Level, Cyclic, and Ramp waveforms are computed periodically in response to the Front Panel commands, and a digital command signal is generated.

The digital command signal is compared with the digitized and conditioned feedback signals from the controlling transducer to produce a digitized error signal. After loop-shaping, the error signal is passed to a digital-to-analog converter (DAC) to produce the servovalve drive signal.

These digital signals are available for monitoring purposes via the ABXY Output connectors. The unswitched analog feedback signals are only available on the Analog Output connector.

In addition to the transducer signals, the Master Controller handles digital input and output signals. These signals are from or to devices such as temperature sensors and controllers, pressure sensors, and similar devices that are used to cause a system Hold, Stop, Reset, Unload, or to stop the actuator in response to Event Detector action. Both digital inputs and digital outputs come through the same connector on the rear panel of the Tower Console.

The optional Data Acquisition card processes up to eight channels of external transducer conditioning and data acquisition. It is intended for use with transducers, such as strain gauges, load cells, extensometers, pressure and temperature sensors and accelerometers, that are not used for control of the servo system. It provides DC excitation to the transducer, and features programmable sensitivity and filtering.

The Sync-Link signal at the Master Controller is a synchronizing clock signal used where multiple Model 8500 Control Systems are used in structures testing situations. Structures testing involves several actuators, each with

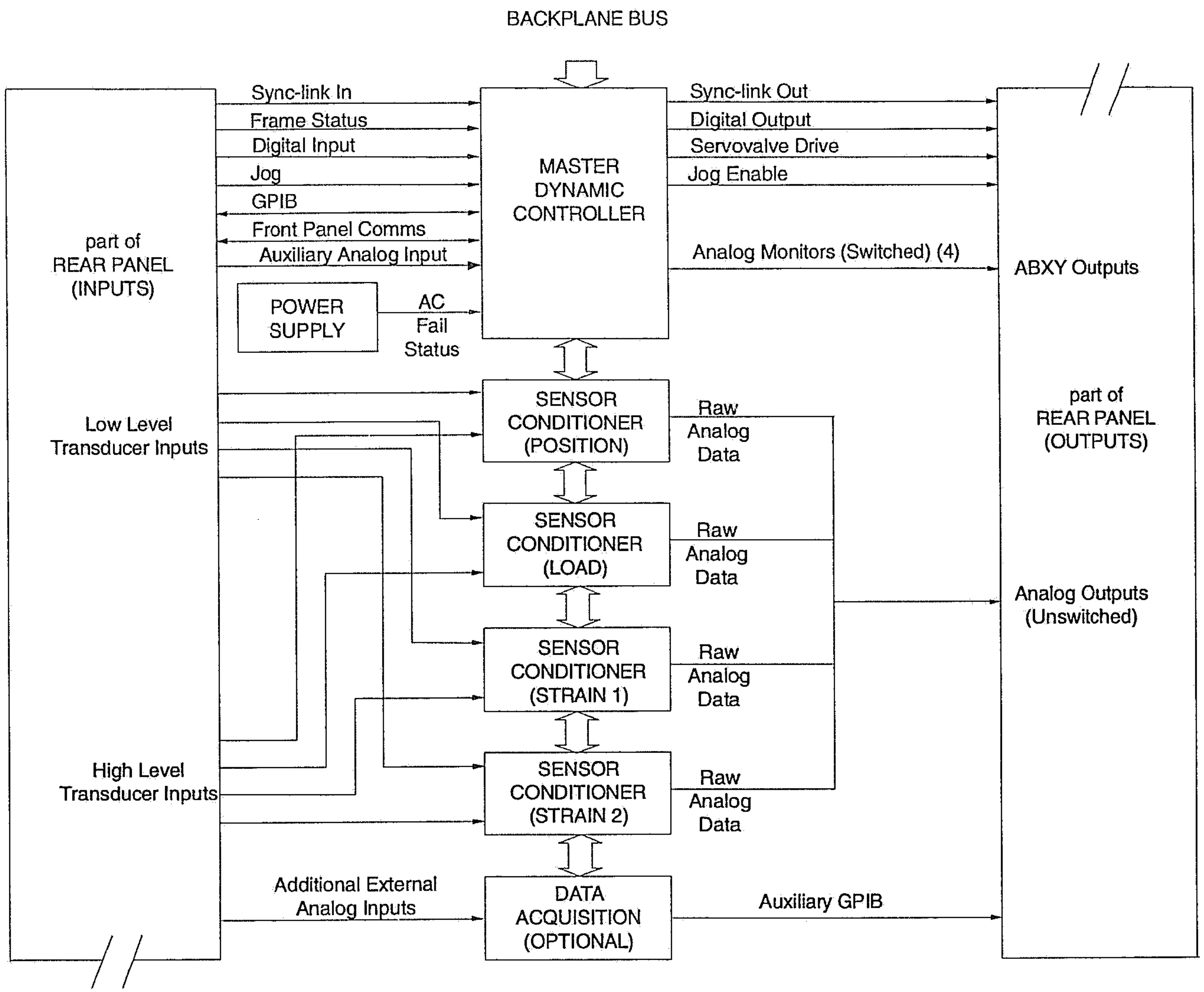


Figure 2–2. Tower Console Functional Block Diagram

its own associated Model 8500 Control System, and include such applications as multi-point automotive chassis testing and aircraft wing loading. Sync-Link is a method whereby all testing channels in the structures system can be coordinated in time, because the same synchronizing signal is sent to all channels.

In addition to its many other functions, the Master Dynamic Controller also processes Status signals from the Load Frame, hydraulic power supply, and the electronic power supply located in the Tower itself.

Master Dynamic Controller Card

Signal handling within the Master Dynamic Controller (MDC) card hardware is carried out using digital processing. Therefore the block diagram of the MDC board in Figure 2-3 shows just one large block depicting most of its functions. Waveform generation, closed-loop control, system status control, Front Panel and GPIB command processing, data logging control, and non-volatile system parameter storage are all digital functions.

Analog-to-Digital Converters (ADC) and Digital-to-Analog Converters (DAC) are employed wherever signal conversion is required. These are shown on the block diagram.

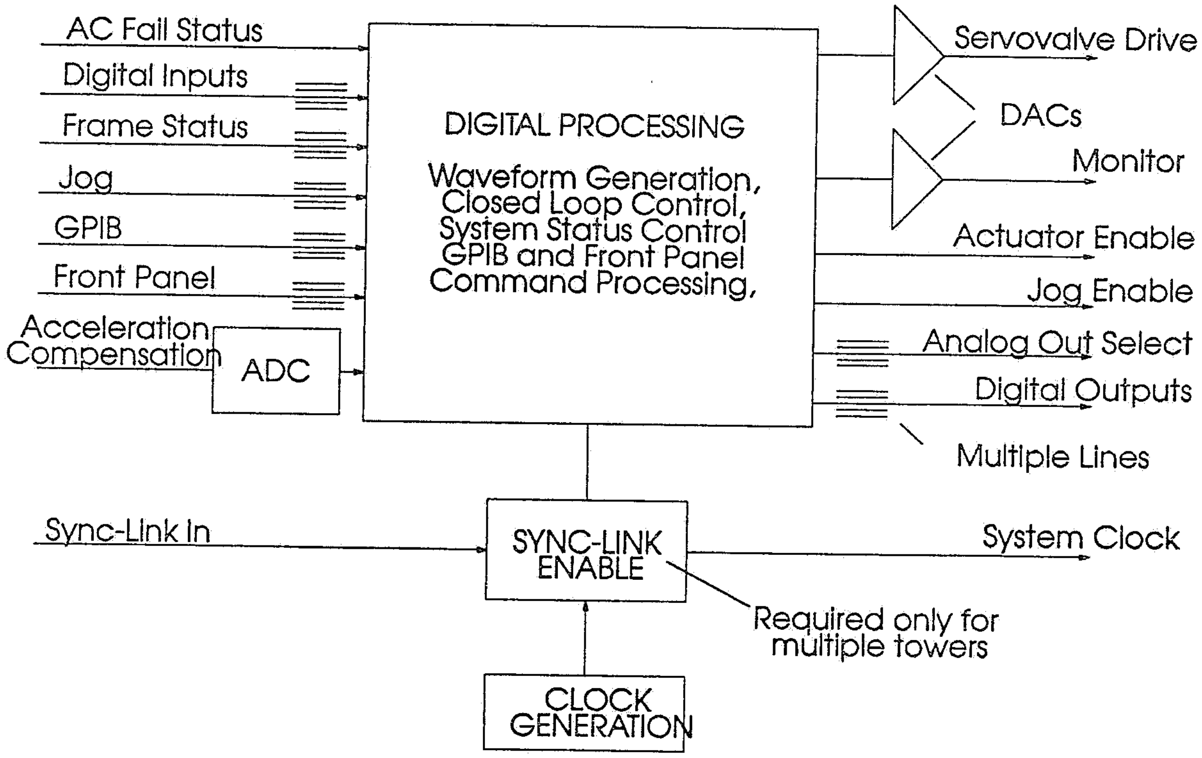


Figure 2-3. MDC Board Functional Block Diagram

An additional function provided by the MDC is the clock signal for the Sync-Link system. This is generated in the Clock Generation block and enabled by the Sync-Link Enable block.

Sensor Conditioner Cards

The four Sensor Conditioner cards in the Tower Console are essentially identical, differing only in the type of transducer with which they are associated. In all cases, they take the high and low level inputs described in the Section “Tower Console”, and depending on the position of Input Selector Switch S1, apply these signals to the processing circuits. A functional block diagram of a typical Sensor Conditioner card is shown in Figure 2-4.

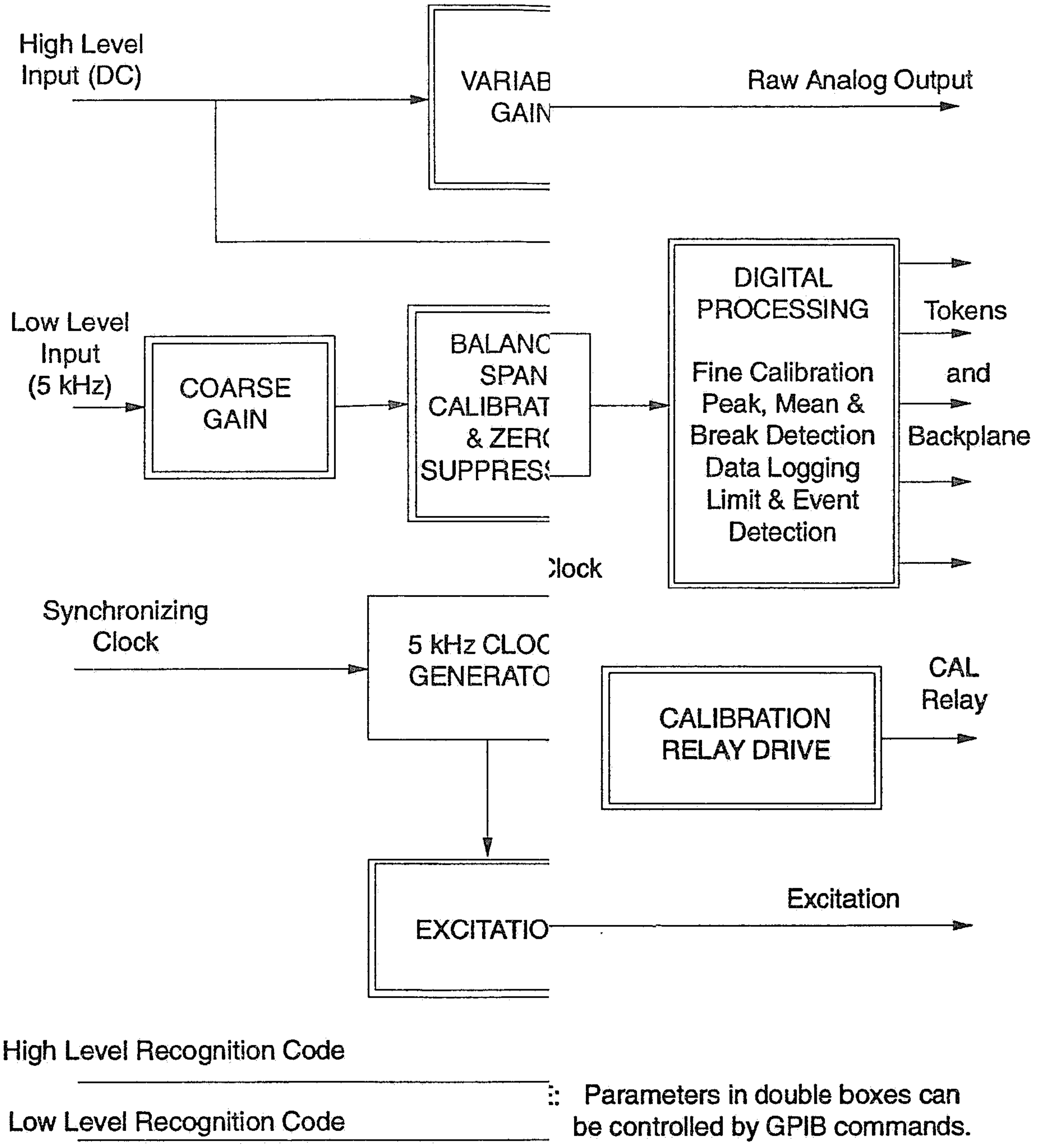
Some of the blocks on the block diagram have double lined boxes around them. This indicates that the functions in these blocks are directly addressable from GPIB commands and their functions can be controlled by an external computer.

Low Level Input

The normal source of input to the Sensor Conditioner cards is from low level transducer signals. These signals are pre-amplified within the Tower Rear Door before input, and they modulate the amplitude of a 5 kHz excitation signal in proportion to position, load or strain. The excitation level applied to the transducer can be set by the firmware to either 5 V or 15 V.

The low level input is first applied to a coarse gain stage. This has four firmware selectable gain settings, in approximate steps of x4, depending upon transducer sensitivity. Selection of the optimum gain maximizes the resolution of the ADC.

The next stage acts to balance out the zero input from the transducer, applies zero suppression when at an off-



: Parameters in double boxes can be controlled by GPIB commands.

set from the zero position and provides a vernier on the span calibration to interpolate between the x4 gain settings described above.

Since AC excitation is used for all transducers, the signal is demodulated before it is sent to the ADC. The demodulator, excitation drive circuit and the ADC can be synchronized to other channels in a structures system through the synchronizing clock pulse brought in from the Sync-Link system.

The low level input is then passed through S1B to a variable bandwidth analog filter. The available bandwidths are 1 kHz, 500 Hz, 100 Hz and 10 Hz, all selectable through the firmware. The system defaults are 1000 Hz for servohydraulic systems and 100Hz for electromechanical systems.

The filtered analog signal passes through the summing junction to a ranging stage. At this point, the raw analog signal is taken off and passed to the rear panel as the input signal for an oscilloscope or a chart recorder. Selection of the correct range optimizes the amplitude and resolution of the signal. Auto-ranging is the recommended setting in normal use, as it allows the ranges to be changed automatically during the running of a test. The ranges can be set by firmware to x1, x2, x4, x8, x16, x32, x64 and x128. Only the first six of these ranges are offered at the Front Panel, the others must be accessed through the Instron Service Functions.

After digitizing, many other operations are applied to the data. These include additional fine calibration, ranging compensation to ensure that the output number remains as an engineering quantity, detection of peaks, means and breaks, and limit and event detectors. Digital filtering is applied to the data, and the filtered data is broadcast to the backplane for system use.

Data logging is also available, as each conditioner card has its own buffer area for storage of data until requested for transmission to a data logging computer.

High Level Input

A previously conditioned high level transducer signal can be input to the rear panel of the Tower Console. Switch S1B routes this signal to the Variable Bandwidth Filter instead of the low level signal. Note that this signal is ranged in the usual way, but it cannot be zero suppressed.

Another possibility is to use the high level signal for compensation. Sensor compensation is selected at Compensation Switch S2 (this is a selectable function at the Front Panel), and is usually used with an accelerometer to compensate for the mass resonance effects of relatively large grips. An accelerometer attached to the load cell can cancel out these resonances when sensor compensation is on by summing the compensation signal with the demodulated low level signal at the Summing Junction following the Variable Bandwidth Filter.

The results of all this processing are tokens that are broadcast on the backplane for use by any or all of the other cards in the Tower, including the Master Controller card.

Transducer Recognition

The connectors for both the low level and the high level transducer inputs contain recognition resistors, and by applying a current through these resistors their value can be read. This enables the Model 8500 Testing System to recognize the characteristics of a particular transducer, such as excitation voltage, sensitivity and whether it is a manually or automatically calibrated device. Switch S1 is used to select the high or low level input, with S1A selecting the appropriate recognition resistor input, and S3 is used to route this to the ADC.

Chapter 3

Command Generation

Outline

- Composite Command .... Page 3-2
- Set Point........................... Page 3-3
- Cyclic Waveforms .... Page 3-6
- Ramp Waveforms.................... Page 3-18
- Constant Amplitude Control .... Page 3-44

Waveforms generated in a digital system such as the Model 8500 are, at their simplest, a series of discrete command values having a certain amplitude and interval. The shape and size of the waveform are determined by drawing a curve through the command values, and the frequency of the waveform is determined by how often the cycle is repeated. The smoothness of the waveform curve is a function of the command interval; the larger the number of discrete values contained within one cycle of the waveform, and the shorter their interval, the higher the resolution will be, and hence, the smoother the curve. The following sections describe how these waveforms are generated, and discuss some of the design considerations that went into the Model 8500.

Composite Command

The Command Waveform which drives the Model 8500 Testing System can be a cyclic waveform, a ramp waveform, or a random waveform. Regardless of the type selected for a test, the command is actually a composite signal made up of a number of discrete elements. It consists of a Set Point component, a cyclic component (if selected), a ramp component, or a combination of both cyclic and ramp components simultaneously. How these elements come together is shown in Figure 3-1. The individual elements are described in the following sections.

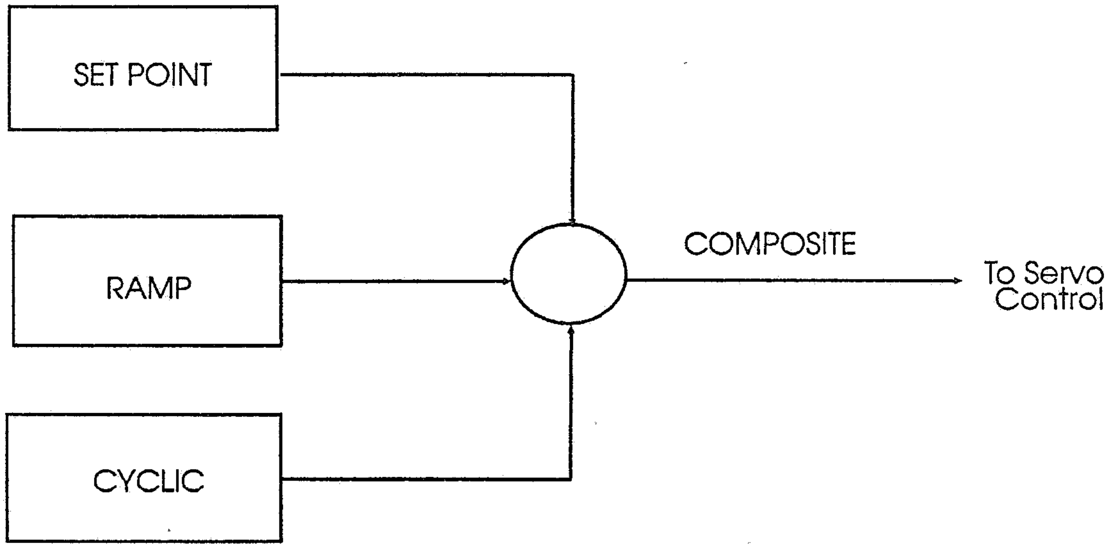


Figure 3-1. Composite Command Signal Generation

Set Point

Definition

Set Point is the static component of the command waveform. It is the starting point for ramps and cyclic waveforms which are superimposed on it, and remains constant unless it is specifically changed by one of the causes described in the next section. Set Point is sometimes referred to as "Mean Level", but this term is not strictly correct, since it is not the mean, or average, of the waveform amplitude excursions, but rather, is a signal level that forms the starting level of ramp or cyclic waveforms. Thus, it may or may not be at zero volts, but is the crossover point for cyclic waveforms or the starting level for ramp waveforms. Set Point is expressed in the units selected for the mode of control for which it is being set (load, position or strain).

Changing Set Point

Once it is set, the Set Point remains constant until changed by one of the factors listed below.

Explicitly

The Set Point can be set or changed by the operator at the Front Panel, using either the rotary potentiometer or the numeric keypad. The details of how to do this are given in Chapter 3 of the Operating Instructions manual. If you know the exact level you want to set, you can enter this number at the keypad, but if you are not sure, or want to approach the Set Level gradually, then use the rotary pot. In either case, the action will be very smooth, but there will be a short delay while the controller processes the request. This happens because a kind of filter action takes place which shapes the transition from the old Set Point to the new Set Point, resulting in a delay of about 0.4 seconds.

Jog Buttons

The Set Point will also change when you use the Jog Buttons on the Hydraulic Control Panel on the front of the Load Frame. If you raise or lower the actuator piston rod (to accommodate shorter or longer specimens, for example), the Set Point will change to a new level directly related to the new position of the actuator. When using the Jog Buttons, there is no delay since the actuator responds instantaneously to the Jog Buttons.

Controller Transitions

The Set Point will also respond to controller transitions such as a control mode transfer or a change in actuator state (from high to low pressure, for example). The Set Point will automatically move to the one selected when setting up the new mode of control before the mode transfer took place, or if a new Set Point was not set up, it will be determined by the operating parameters of the new mode. In either case, the change is considered implicit, because the operator has not specifically commanded a Set point change.

Ramp Waveforms

When using Ramps as the command waveform, the method you use to terminate the ramp can have an effect on the Set Point. Normally, the ramp generator will go to a HOLD state when the ramp waveform has finished. If you now press RESET, the ramp waveform will go back to its starting point and the Set Point is unaffected. However, if you press FINISH when the ramp has completed its excursion, the Set Point will be automatically reset to the current end point level. Again, this is an implicit change, so be aware of what happens to the Set Point when you use the FINISH key to end a ramp.

Random Waveforms

Random waveforms are made up of a number of ramp segments, each of which has a beginning level, a slope, and an end level. When a random waveform is running, the Set Point is automatically set to the end level of each segment as it is completed. Thus, the Set Point changes often during random waveform generation, and will end up at the end level of the last random waveform segment that ran.

Cyclic Waveforms

Cyclic Waveform Generation

Cyclic Waveform Generation encompasses three distinct steps. First, the argument or mathematical expression of the waveform function must be generated; second, the waveform function itself (sine, square, triangle, etc.) must be generated; and finally, the amplitude is scaled. Resolution and accuracy of the function are discussed at the end of this section. Figure 3-2 will give a better understanding of how these elements interact.

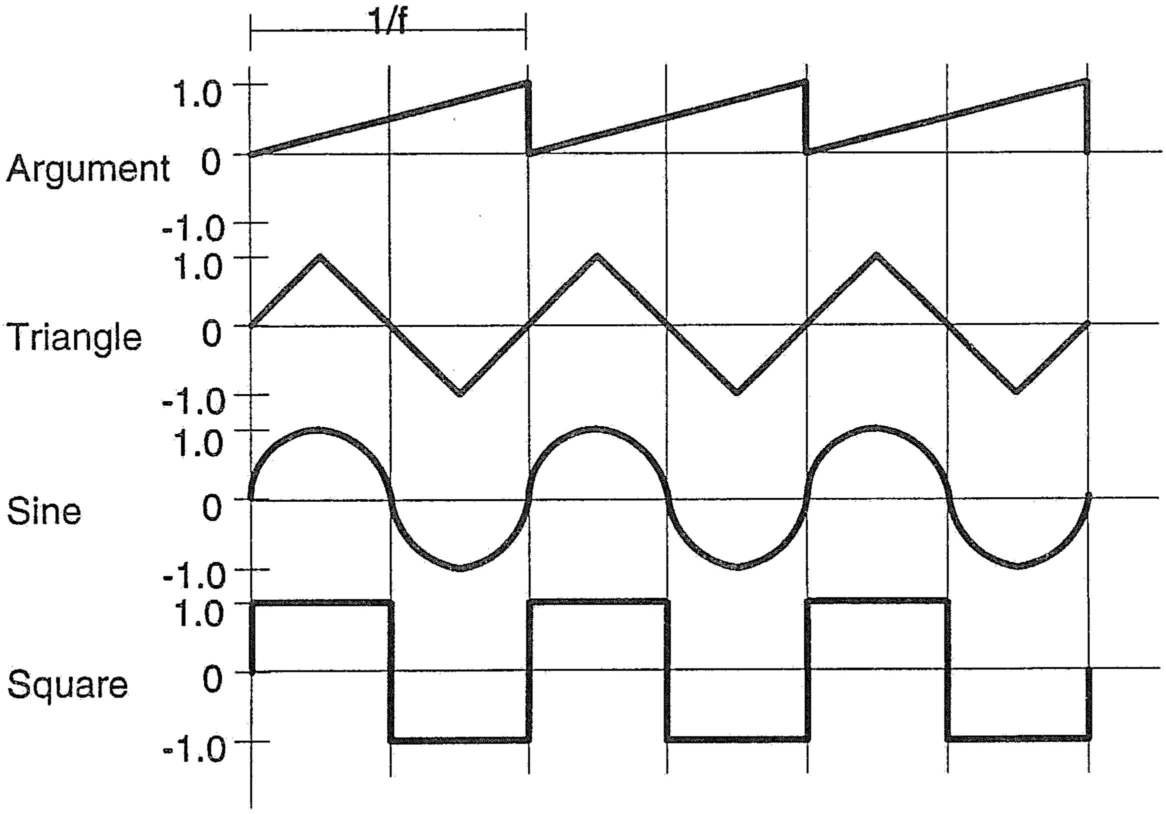


Figure 3-2. Function Generation

The Sample Clock, used throughout the system for timing, is used to set a period for the waveform (shown as 1/f at the top of the diagram). Coupled in the Argument Generator with frequency commands set at the Front Panel controls, a sawtooth waveform is derived which forms the basis for all of the cyclic waveforms. The sawtooth waveform is modified in the Shape Generator, where the waveshape function (sine, triangle, square) is derived. Selections from the Front Panel determine which function will be generated. From here, the amplitude is scaled, again using instructions from the Front Panel, for the final Waveform Generator output. This is shown functionally in the diagram of Figure 3-3.

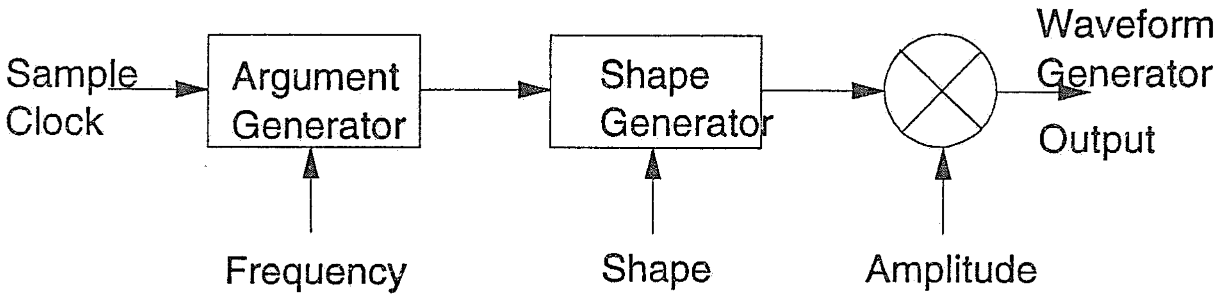


Figure 3-3. Waveform Generator Diagram

Cyclic Waveform Generator States

Before we look at how individual waveforms are generated, we should understand the operational states of the Waveform Generator itself. There is actually only one waveform generator in a Model 8500 Testing System, even though each Mode Controller has its own set of setup parameters for operating the Waveform Generator. Each Mode Controller can be preset separately for waveform, frequency, and amplitude before it is placed into operation. During a mode transfer, control of the Waveform Generator is passed from the Mode Controller currently in control of the system to the Mode Controller taking control. The Waveform Generator thus suspends what it was doing under the old mode of control, and begins operating under the setup parameters of the new control mode. This operational switching is very rapid, and therefore gives the impression that two separate Waveform Generators are in operation.

Current operational parameters and preset setup conditions require that the operating states of the Waveform Generator be carefully controlled. In addition to the Waveform Generator setup commands, the Waveform Generator Test Controls buttons on the Front Panel provide direct operator intervention. The START, HOLD, FINISH, and RESET keys set the state of the Waveform Generator for the mode of control currently commanding the testing system.

Controlling the Waveform Generator States

The Waveform Generator has several operating states. At any given moment, it can be Stopped, Running, Held, Finishing, or Resetting, or *it can be in a transition between these states.* Transitions from the current operating state to most other states is allowed, but certain transitions are not, for safety reasons or because a certain transition is not logical. It would make no sense, for example, to go from the Stopped state to the Held state. Trying to determine all the possible combinations of transitions soon becomes complex and confusing. To simplify matters, a State Diagram will help you to see which transitions are possible and how they occur.

Waveform Generator State Diagram

The State Diagram in Figure 3-4 shows the discrete states of the Waveform Generator. The three main states, corresponding to illuminated markings on the Front Panel, are Stopped (END), RUNNING, and HELD. The secondary states of Finishing, which also has a lit Front Panel marking, and Resetting are temporary states, because they will automatically transit to the Stopped state when they have completed their action.

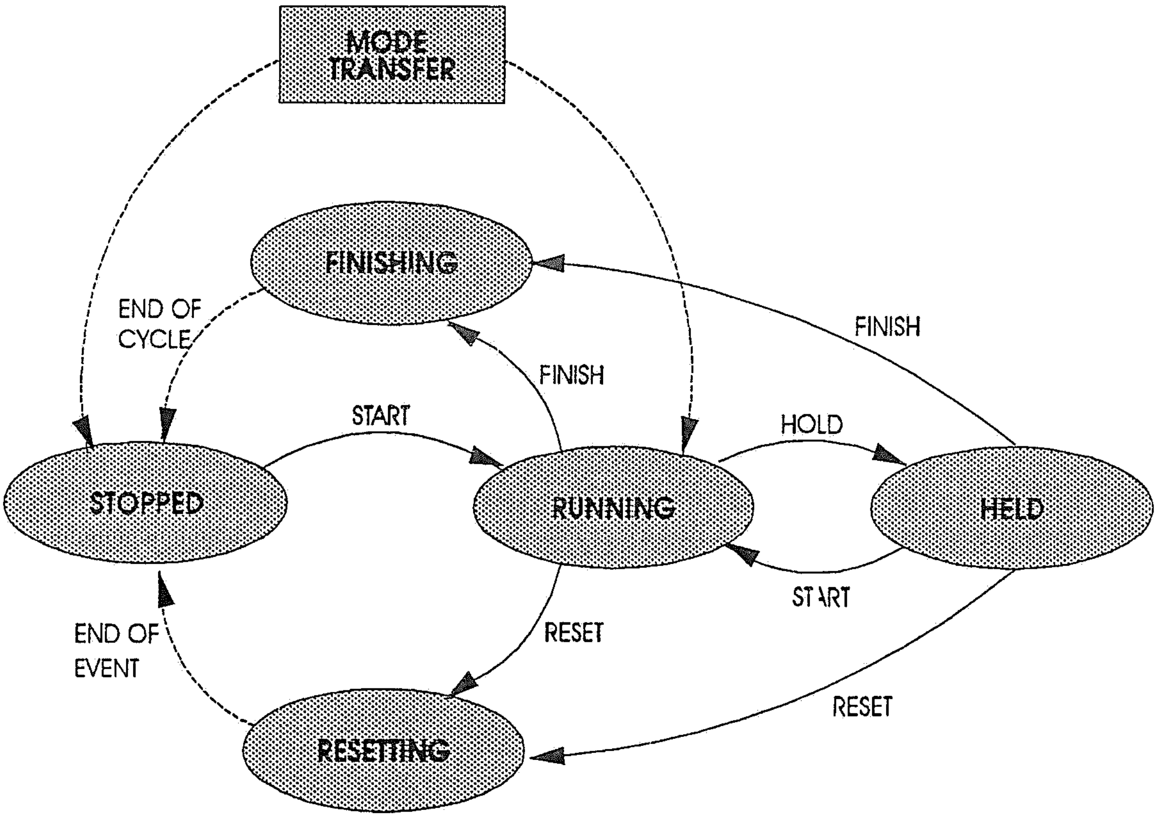


Figure 3-4. Waveform Generation State Diagram

Curved lines running between the various states indicate the possible transitions from one state to another. These lines are labeled with the Front Panel keys or with the GPIB Commands that initiate the transition. The dashed lines running from the Finishing and Resetting states to the Stopped state indicate the temporary nature of these states, and their labels show how these transitions occur. The Finishing state completes its action by completing the last cycle before transiting to the Stopped state, while the Resetting state ramps the amplitude of the waveform to zero before stopping. These are indicated by the End of Cycle and End of Envelope labels, respectively.

A special transition case exists during a mode transfer from one mode of control to another. Depending on how the Waveform Generator in the target mode has previously been set up, the new waveform generator state may be either Stopped or Running. This is shown by the heavy dashed lines running to the Stopped and Running states from the Mode Transfer block.

Argument Generation

You will remember from the "Cyclic Waveform Generation" Section that waveform generation is a three-step process. The first step is argument generation. The Argument Generator provides a sawtooth waveform that is the basis for all other waveforms. The sawtooth waveform has unity amplitude and a frequency f, (or a period of $\frac{1}{f}$) based on the sampling clock. The Argument Generator is a digital function that changes linearly with time at a rate specified by frequency (f). To be precise, we should write the argument function in terms of update period as $f\,n\,T$ where n is the number of updates since the function generator started, and T is the sampling period (for example, 200 microseconds for a 5000 Hz sampling frequency). The argument is represented by a 31-bit integer that is incremented once per update period while the function generator is running. This statement may be expressed as:

$$(f \cdot n \cdot T) = f(n-1) \cdot T + f \cdot T$$

where the term $f{\cdot}T$ represents a constant increment per update period. To think of the argument and increment in terms of a 31-bit integer requires that we scale it by the maximum value of the integer (7FFFFFFF hex).

Shape Generation

We have just seen how the argument of a cyclic function is generated. Turning now to shape generation, we will see how the various cyclic waveshapes are generated. We will start with the sine function, since it is the most complex, and work toward the simplest.

Sine Function Generation

The sine function (y) is usually described by the mathematical expression:

$$y = A\ \sin(2\,\pi f\,t)$$

Only $f\,t$ is actually computed since 2π is simply a constant and is accounted for in the method used to generate the sine function. The amplitude scaling factor, A, will be handled later by the amplitude scaling function.

The Model 8500PLUS uses polynomial functions to approximate the sine function. As an example, hand-held calculators and programming language libraries commonly use polynomial approximations. This method has the advantage of high accuracy over the full range of the function.

Triangle Function Generation

Triangles are generated as a linear function of the argument. Each cycle of the function is considered in three segments. The first segment begins when the argument is zero and continues until the argument reaches the value of one quarter. Beginning at this point, the second segment starts and ends with an argument value of three quarters. The third segment continues until the argument reaches one. Each of the segments is described by a linear equation as follows:

Segment 1: $f = 4\,arg$ for $0 \leq arg < 0.25$

Segment 2: $f = 1-4(arg-0.25)$ for $0.25 \leq arg < 0.75$

Segment 3: $f = 4(arg - 0.75) - 1$ for $0.75 \leq arg < 1.0$

where *arg* represents the function argument and *f* is the triangle function.

Square Function Generation

Square waves are generated as functions of the argument, just as are sines and triangles. The square wave function is either plus one or minus one for any value of its argument while it is running, and is equal to zero when not running. The square wave function may be described mathematically as follows:

$$f = 1 \qquad \text{for } 0 \leq arg < 0.5$$

$$f = -1 \qquad \text{for } 0.5 \leq arg < 1.0$$

$$f = 0 \qquad \text{when not running}$$

Haver Function Generation

Each of the haver functions (haversine, havertriangle, and haversquare) is derived from the basic function (sine, triangle, and square). The fundamental operation is to phase shift and offset the basic function so that a waveform results that is unipolar. This operation may be described mathematically as follows:

$$haverfunction = \frac{1 + function(arg - 0.25)}{2}$$

External Waveforms

Externally generated analog waveforms are handled as a special case of waveform shaping. The analog waveform is introduced to the system either by way of a special user transducer adapter plugged into the DC Input of a sensor conditioner card, or by way of the AUX IN connector. In the first case, the sensor digitizes the analog signal and provides digital data to the Waveform Generator. For the AUX IN case, the signal is digitized on the controller board and the data is then supplied to the Waveform Generator.

When the waveform shape is selected as External, the Model 8500 does not need to perform argument or shape generation as was shown in Figure 3-3. Instead, the argument generator is bypassed and the shape generator passes the digitized waveform data straight through. Figure 3-5 shows the block diagram of Figure 3-3 with this function included. The Amplitude Scaling function remains in the signal path and allows the external waveform to be scaled.

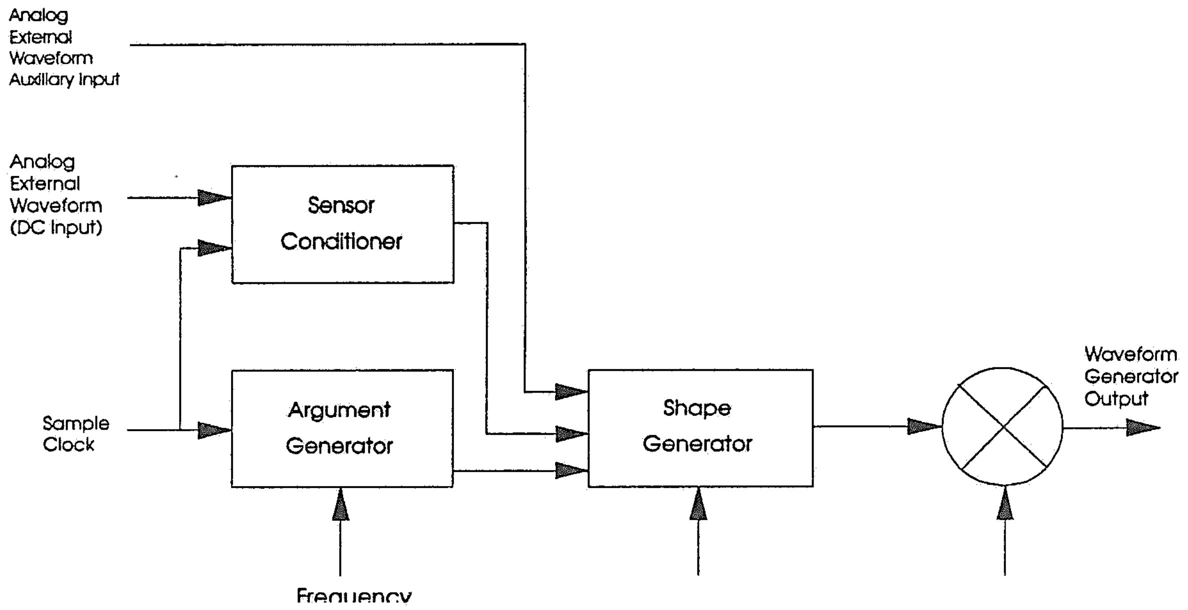


Figure 3-5. Waveform Generator with External Waveform Input

The state diagram we saw in Figure 3-4 is simplified when using external waveforms because the FINISHING and HELD states do not exist. When the Waveform Generator is in the STOPPED state, the amplitude scale factor is zero. When the Waveform Generator is placed in the RUNNING state, the amplitude scale factor ramps from zero to the user-specified value in the specified envelope start time. When the Waveform Generator is placed in the RESET state, the amplitude scale factor ramps to zero in the specified envelope reset time.

The sensor card performs all its normal functions on the digitized data, just as if it were a feedback signal. The output is a 32-bit number, the same output as the normal output from the shape generator. The Waveform Generator amplitude scaling is also performed identically to the normal waveform.

Amplitude Scaling

Step three of the waveform generation process is to scale the output of the Shape Generator by the amplitude parameter *(A)*. Waveforms are scaled by an amplitude parameter according to the needs of the user. Amplitude is represented as a 32-bit floating point number, made up of a 24-bit mantissa and an 8-bit exponent.

Accuracy and Resolution

Waveform accuracy and resolution are a measure of the quality of waveform synthesis. Accuracy is a measure of how closely the generated waveshape resembles the ideal. Resolution is a measure of the smoothness of the waveform.

Sine Wave Accuracy

The Model 8500PLUS sine wave generator uses a polynomial approximation to calculate the sine function in real time. It is based on the algorithm from Software Manual for Elementary Functions, Cody and Waite, Prentice Hall 1980, Chapter 8. Using this algorithm, the Model 8500 calculates the sine as a 32-bit floating point number, with a 24-bit mantissa and 8-bit exponent. The accuracy varies slightly over a complete cycle, but is never worse than 0.0004% of reading.

Sine Wave Resolution

Resolution is a measure of how smoothly the waveform changes. We can quantify resolution as being the smallest possible change in the waveform that can be generated. As a result of the sine wave generation algorithm, all 32 bits of the argument are significant. Since the sine function has a continuously changing slope over each cycle, we can define resolution as the point where the slope is greatest. For a sine function, this value is 6.28. Therefore, worst case resolution may be defined as 6.28 parts of 2^{31} or about 3 parts per billion of sine wave amplitude.

Triangle Accuracy and Resolution

Triangles are simply related to the argument by a multiplication, so there is no error incurred. Triangle accuracy is determined strictly by the precision of the arithmetic, which is 1 part of 2^{23}.

Resolution of the triangle is readily determined, knowing that the magnitude of the slope of the triangle relative to its argument is equal to 4 at any point within a cycle. For a one-count change in the argument, there will be a four-count change in the function, the smallest possible change of the triangle waveform. Therefore, resolution of the triangle is defined as 4 parts in 2^{31} of triangle amplitude.

Frequency Accuracy

Two factors determine the accuracy of waveform frequency. One is the precision with which frequency may be specified, and the other factor is the accuracy of the clock oscillator that serves as the time base for the system.

Waveform frequency is stored in 32-bit binary integer format, with the value 7FFFFFFF hexadecimal representing a frequency of 5000 Hertz. Precision of the number representing frequency is fixed at 5000 parts of 2^{32}. This means that frequency precision related to frequency setting, varies. For example, a frequency of 50 Hertz may be set with a precision of 0.00000232 percent of setting, but at a frequency of 0.0001 Hertz, the precision becomes 1.16 percent of setting.

The accuracy of the time reference clock oscillator is 0.01 percent. Frequency accuracy will be directly influenced by the oscillator accuracy so that frequency accuracy will be 0.01 percent of setting over the full range of possible waveform frequencies.

There is a range of frequencies over which the fixed precision error dominates, and another over which the oscillator accuracy dominates. At higher frequencies, the oscillator accuracy is dominant, and at low frequencies, the limited precision of parameter storage dominates. At frequencies higher than the frequency at which parameter precision is 0.01 percent, accuracy is primarily determined by oscillator accuracy, and at frequencies lower than this boundary, accuracy is primarily determined by parameter precision. The critical frequency is 0.01 Hertz. Therefore, we can say that frequency accuracy is 0.01 percent of setting for frequencies from 0.01 Hertz to 1000 Hertz, and is constant at 0.01 percent of 0.01 Hertz (10^{-6}) for frequencies below 0.01 Hertz.

intervention or a computer program command is then required for a transition to another state, such as Resetting or Stopped. Note that the ramp generator cannot be restarted (go back to the Running state); it can only go to the Resetting or Stopped states.

Another special case exists for the Resetting state. When a Reset command is issued from the Running or Holding states, either by the operator or the control program, the Ramp Generator goes to the Resetting state. The Resetting state, however, is only a temporary state until the fixed, non-programmable reset ramp to the original Set Point finishes. At this point, the Ramp Generator automatically goes to the Stopped state, as shown by the dotted line between the Resetting and Stopped states in Figure 3-6.

As we saw with the Cyclic Waveform Generator, a Control Mode Transfer can also cause a change of state. All of the transitions shown on the diagram correspond to GPIB commands, as well as Front Panel commands, except the End of Reset transition.

Ramp Generation

In its simplest form, a ramp waveform is made up of a constant ramp rate (slope) and an end point (amplitude). In a Single Ramp, the waveform proceeds at a constant rate until the end point is reached, and then stops. At this point, it has completed its cycle and cannot be restarted; a new ramp must be commanded to cause the ramp to repeat or start a new cycle. Also, the system Set Point, from which all ramp waveforms begin, is automatically set to the current end point of the last ramp. This means that the Set Point must be reset to its original value in order to repeat the previous ramp exactly. All of this is illustrated in Figure 3-7.

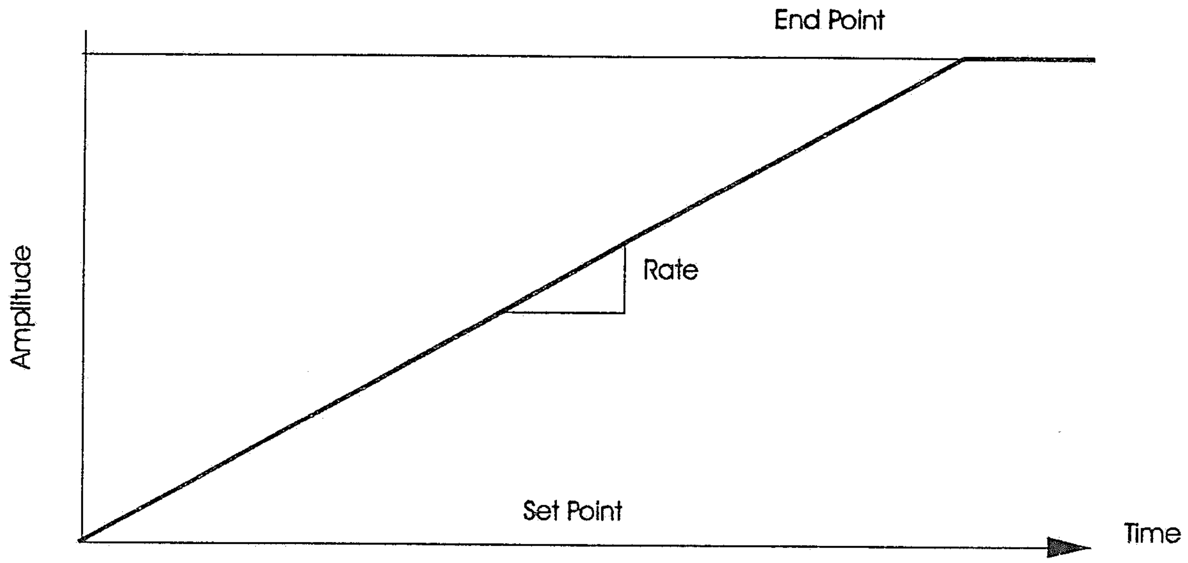


Figure 3-7. Single Ramp Waveform

As we mentioned, when using single or dual ramps, the waveform ends when it reaches the last end point. It will then hold at that level until the operator does something, or the computer control program issues a new command. If you choose to repeat the original ramp, you would choose RESET at the Front Panel to return the waveform to the original Set Point. The waveform would then return to the Set Point at a fixed, non-programmable rate of 0.5 full scales per second, and you would then restart it, as shown in Figure 3-8. If you did not select RESET before restarting the ramp, it would begin at the previous end point and continue on up to full scale.

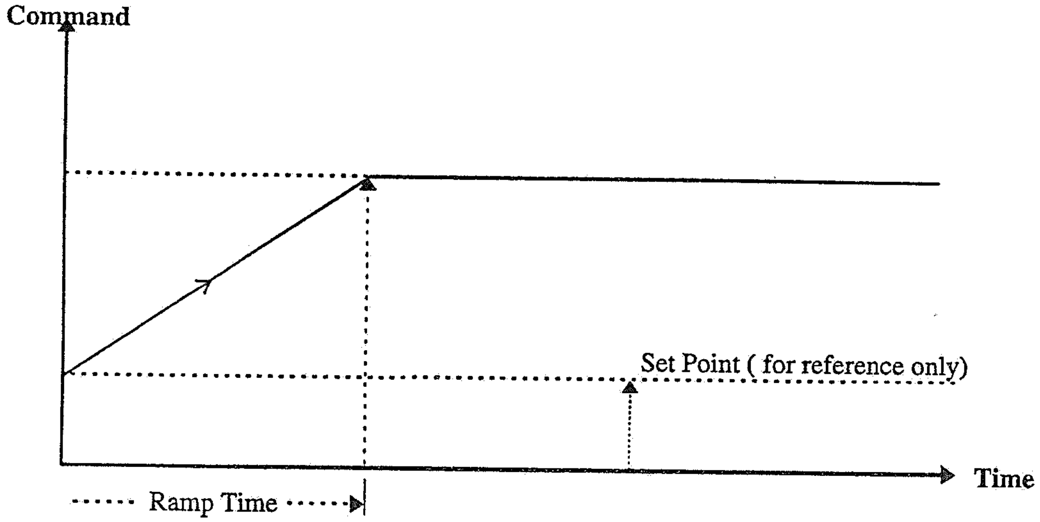
You also have the option of pressing FINISH at the Front Panel. You would most likely choose this option if you will not be running another ramp. In this case, the command issued to the Model 8500. Finally, a command to start the ramp running must be issued. All of this takes time and computer overhead, and can result in noticeable "gaps" in the waveforms.

The Model 8500 PLUS incorporates a new ramp waveform type, called an *absolute ramp*, to handle these block transfer situations more gracefully and efficiently. This waveform has the same operational states – Stopped, Running, Holding, and Resetting – as the single ramp waveform. However, an absolute ramp is specified in terms of an *absolute end point* (Command 4), *i.e.*, one that is independent of the set point, and a ramp *time* in seconds (Command 86). See Figure 3-12 for examples of absolute ramps.

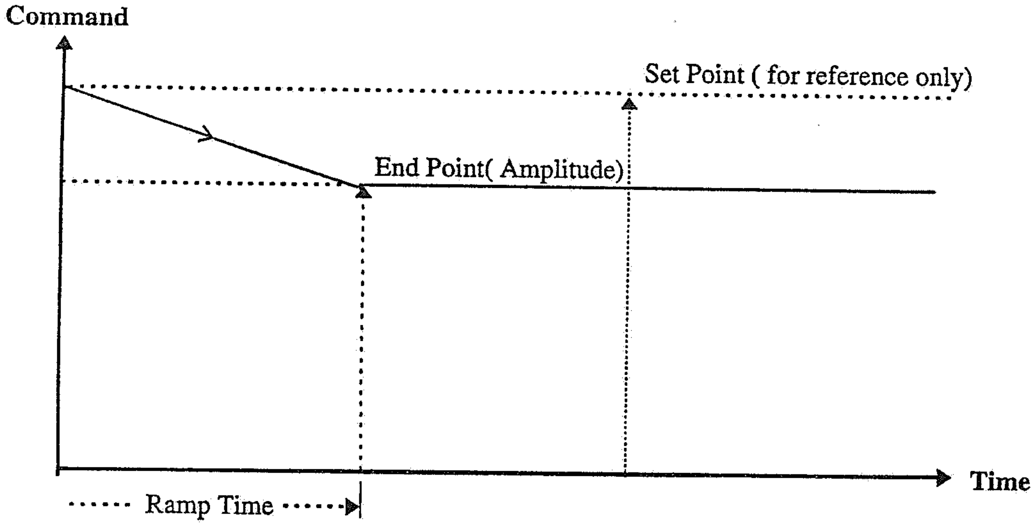
Absolute ramps automatically run in the direction of the desired end point, and take the exact amount of time specified before reaching the Holding state. If the set point or amplitude changes while the ramp is running, the end point may be achieved in less than the specified time. In this case, the end point is held until the specified amount of time has elapsed, and then the ramp goes to the Holding state.

To complement the absolute ramp waveform, another waveform called *absolute hold ramp* is also available on Model 8500 systems. When this waveform is in the Running state, it remains at the current set point for the specified amount of time (Command 86), and then goes to the Holding state. It is intended as a convenient way to allow block programs to dwell for a specified amount of time at an arbitrary set point that was achieved by an earlier block.

Note *Due to their special natures, neither absolute ramps nor absolute hold ramps are accessible from the Front Panel.*



(a) Set point less than end point



(b) Set point greater than end point

Figure 3-12. Absolute Ramp Waveforms

with the next buffer automatically, regardless of whether it has new data in it or not (unless the buffer is being loaded). The C46 command description in the Model 8500 GPIB Manual provides information on how this is handled by the computer.

The buffers can be commanded to operate in a Constant Time Mode or a Variable Time Mode. In the Constant Time mode, the buffer is loaded with segment end points (up to 400 total per buffer), while segment duration is specified just once and applies to each segment defined in the buffer. When in Variable Time mode, both the end points and the durations are specified for each segment. The number of segments is limited to 200 per buffer in this case.

Random waveform execution begins with the buffer most recently loaded when the Start Random Command is executed (C1,7 or C1,8). When the buffer loading begins, the buffer is marked as not ready so that waveform generation will automatically hold if the current buffer execution ends before the next is loaded. At the end of the last segment of the buffer, waveform generation ceases if the buffer is marked as terminal. Otherwise the status of the next buffer is checked and if it is ready, execution continues immediately with the first segment. If it is not ready, waveform generation holds until it becomes ready (it is not ready while the buffer is being loaded).

Continuous waveforms may be generated for an arbitrary number of segments by loading segment definitions while a buffer is executing. When random waveform generation starts, and at each transition from one buffer to the other, a status report (S1,6) is generated. At this time, it is known that a buffer is available for loading with new data and that the execution time of the current buffer is the amount of time available for loading.

Demand Hold

Demand-Hold is a feature of the Ramp Waveform Generator that is used in tests where the applied command waveform is "held" at each successive waveform end point until the feedback value has achieved that end point value (or close to it). In this way, you can ensure, in life-testing of a component for example, that the most damaging load peaks have indeed been applied to the component. Monitoring the difference between the command and feedback, the mode controller producing the successive commands could be placed in Hold for several loop update intervals until the error between command and feedback was sufficiently small.

As shown in Figure 3-15, a variable Demand Window can be set up that determines how long the command waveform will be held, and when it will be restarted. The width of the window can be set to a wide or a narrow value, thus determining how closely the feedback adheres to end point peak values.

The Demand-Hold feature attempts to overcome system dynamic constraints to guarantee that specified segment end point are achieved while running Random Waveforms. At the end of each segment, the difference between the commanded end point and the tracking feedback (controlling error) is examined. In many cases, the feedback lags the command so that the controlling error is not zero. If, at the end of the segment, the magnitude of the error is greater than the specified Demand Hold window, the command is held at the value of the

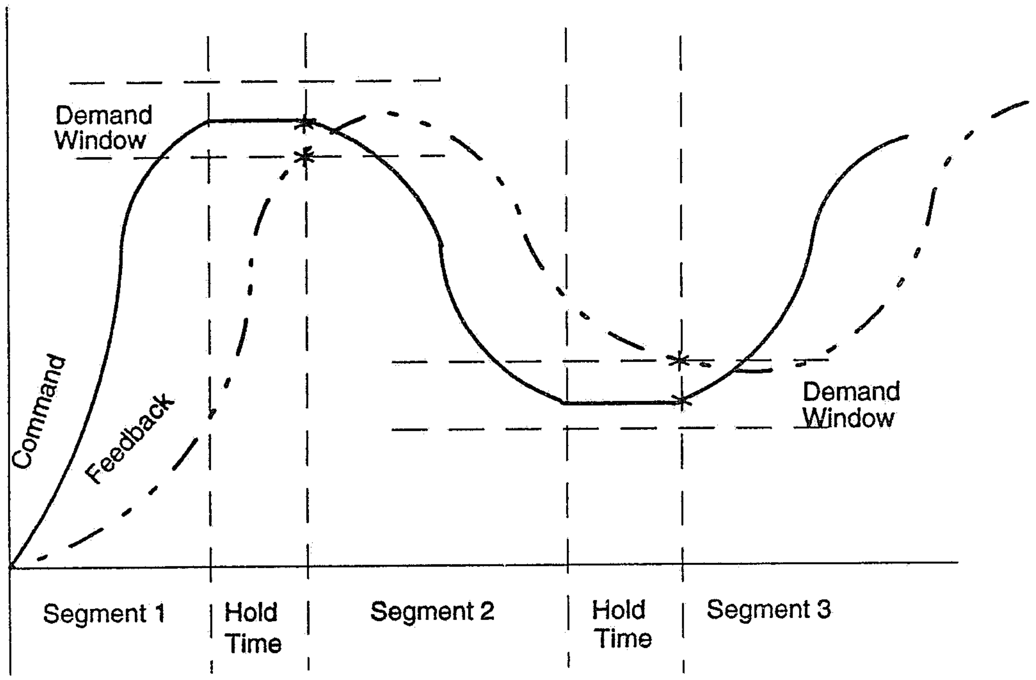


Figure 3-15. Demand-Hold Diagram

segment end point until the magnitude of the error decreases to within the window, and then the segment begins to run.

Demand Hold Dynamic Considerations

Dynamic behavior of the system with Demand Hold active depends strongly upon three factors; closed loop dynamic response (loop shaping), Demand Hold window size, and hydraulic fluid flow saturation (velocity or slew limit). When segment amplitudes are relatively small and the system can supply enough hydraulic fluid to meet the velocity demand, then the tracking error is due to the dynamic response of the control loop.

If the loop gain is low, there will be a relatively large error between the command and feedback, and Demand Hold will hold the command at the end of the segment waiting for the feedback to catch up. Because the loop gain is low, feedback will probably approach the held command level asymptotically until the Demand Hold window level is reached. At this point, the command starts tracking the next segment. In this case, the feedback will probably have achieved something less than the command segment end point (but still within the window).

On the other hand, if loop gain is high and the loop transient response overshoots a step change in command, it is likely (for small Demand Hold windows) that the feedback will overshoot the segment end point. This is due to the fact that feedback most likely is changing at a high rate when it crosses the window threshold, and continues in the same direction for a certain time even though the next segment is going in the opposite direction.

When large segment amplitudes at high rates are required, it is likely that the system cannot supply enough hydraulic fluid to meet the demand. In this situation, the actuator slews at some limited velocity and the tracking error builds until feedback crosses the Demand Hold window threshold. This situation is likely to induce some overshoot (particularly for small windows) since the actuator will continue to slew in the same direction until the error is reduced to the point where hydraulic fluid flow is not limited. In addition, if controller integrator gain is not zero, there will be some integrator windup that must be overcome before the actuator direction is reversed, contributing further to overshoot.

In summary, there are three factors that affect Demand Hold dynamic behavior. Small window values force the feedback to achieve the command end points more closely, but are more likely to cause overshoot. Overshoot depends on the closed loop dynamic response (loop shaping) and on hydraulic fluid flow saturation effects. Thus, it may be necessary to experiment to determine optimum window values for a particular test.

Sampled Data Playback

Data that has been recorded and digitized may be run on the Model 8500 to recreate the conditions of an original test. Information is represented as digital samples taken at a fixed rate. Sampled Data Playback (SDP) is a mode of the Ramp Generator that provides the means to create a loop command that corresponds to the original data.

Traditionally, with analog controllers, sampled data is fed to a Digital-to-Analog (D/A) converter at the same rate that the data was originally sampled. This results in a staircase waveform with each step corresponding to the amplitude of the original signal at the sampling instant. The staircase is filtered to smooth the steps and present a continuously varying replica of the original signal to the loop controller (see Figure 3-16). Critical to the performance of this approach is the smoothing filter. Typically, low-pass, high-order filters are used that must be tightly specified so that in multi-channel applications, the filters are phase matched throughout their pass bands.

No D/A converter is required with a digital controller. If the data were sampled at the iteration rate of the controller, then playback would be a simple matter of presenting the data samples directly to the controller as commands. No filtering would be required. However, it is unlikely that data is sampled at the controller rate and it is impractical to change the controller rate to match that of the sampled data. Typically, data may be sampled at 204.8 samples per second, but the controller iteration rate is 5000 updates per second. A method of resolving the mismatch between data rate and controller iteration rate is needed.

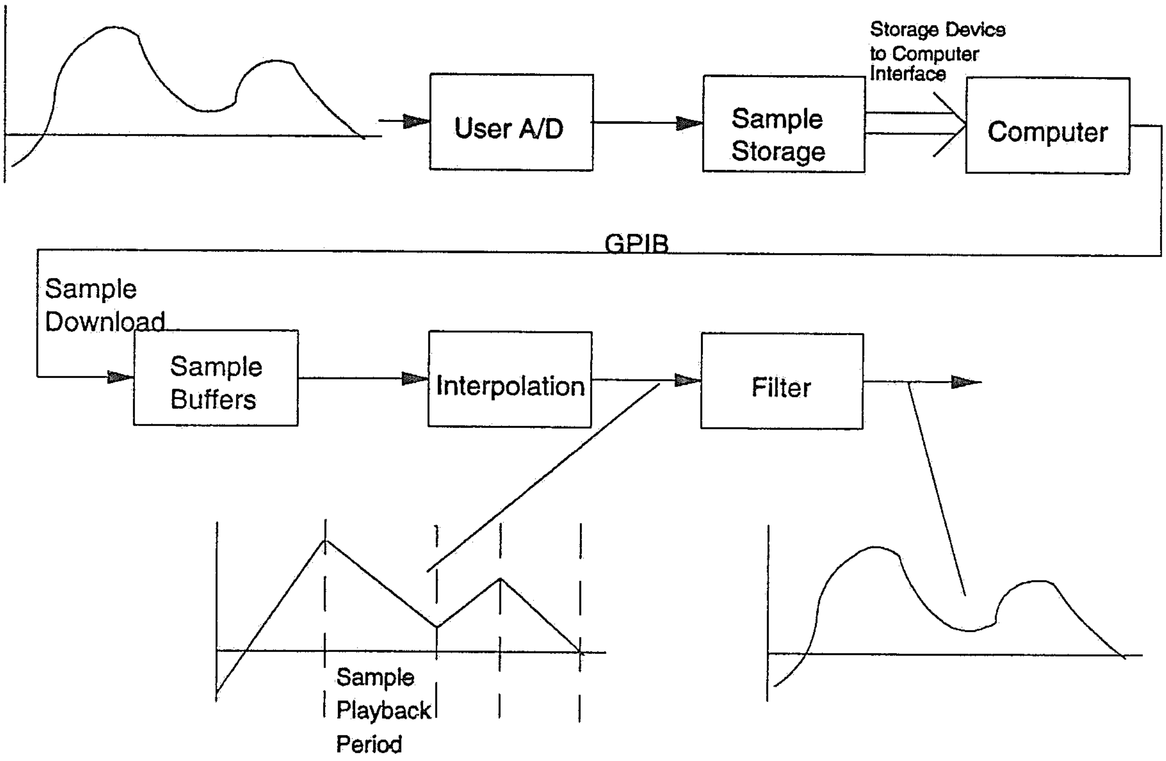


Figure 3-16. Sampled Data Playback Block Diagram

The problem is one of interpolation, in which the controller needs valid command data every iteration period, even though there may be a new data sample only every 4 or 5 periods. It is solved by filling in the gaps with interpolated data every iteration time. This is done by first using linear interpolation, and then digital low-pass filtering on the result. Linear interpolation fits straight lines between the data samples, and filtering rounds out the lines so that the transitions from one line segment to the next are smooth and continuous.

Data is transferred to the Model 8500 in a way that is similar to that of random segment data. Blocks of samples are transferred in a binary format (data is signed 16-bit). Data is stored in two buffers; one may be loaded while the other is being played so that playback is uninterrupted by data loads. Each block of sampled data is preceded by a header that contains a number of parameters associated with that data block. These header parameters specify the number of samples in the block, amplitude scaling of the block, and block execution mode.

Interpolator

The interpolator must fill in the gaps between data samples. It does this by fitting a straight line between successive pairs of data samples and constraining interpolated data to fall on this line. This is accomplished by computing the difference between successive samples and scaling that difference by the number of controller iteration periods per data sample periods. For example, if the sampled data rate is 200 samples per second, then the scaling factor is $\frac{200}{5000}$ or 0.04. Then, on each controller iteration, the scaled difference is added to the previous interpolated data point. This continues for the number of iteration periods between sampled data periods, or in our example, 25 intervals. At the end of each interval, a new scaled difference is computed, and the process is repeated. An important feature of the interpolator is that it works even when the number of interpolation intervals is not an integer (e.g., when the sampled data rate is 204.8 samples per second).

The sampled data rate parameter is stored as a 32-bit integer that represents an increment used in determining the length of the interpolation interval in units of controller update periods. The precision of this parameter is ±5000 parts in 2^{32} (or 5 parts in 2^{29})for our update rate of 5000 iterations per second.

Filter

The output of the interpolator is a waveform made up of a series of straight line segments joined at their ends. A digital IIR (Infinite Impulse Response) filter is used to round and smooth the waveform so that the result looks very closely like the original signal waveform before sampling.

The filter[1] is designed as three cascaded sections. Each section implements a second-order stage of the filter. The filter may be programmed to be either Butterworth, Chebyshev, or Elliptic, and the bandwidth of the filter is settable over a range of approximately 1 to 60 Hertz.

Amplitude Scaling and Envelope

Data to be played back through the Model 8500 is typically collected from transducers other than those used on the testing system. For example, load values may have a full scale representation of 1000 pounds, while the testing system load cell has a full scale rating of 20,000

---

(1) For more information on signal interpolation and filtering, see:
Digital Signal Processing, by Alan V. Oppenheim and Ronald W. Shafer,
© 1975 Prentice Hall

pounds. The data is scaled by a factor (i.e. $\frac{1}{20}$) to make it compatible with the testing system full load cell. It is important to note that this scaling operation does not reduce the precision of the data, since the full 32 bits of the results of the scaling multiplication are retained.

Amplitude scale factors are handled as floating point numbers with a 16-bit mantissa. The number is normalized so that precision is never less than ±0.003 percent of setting. This amplitude scaling is applied throughout the test. The scale factor is applied globally to all playback data samples.

Another form of scaling is enveloping. In this case, scale factors associated with each buffer of data are applied to the playback samples. When a transition is made from one buffer to the next, the envelope scale factor is changed smoothly from one to the next at a rate that is specified separately. The intent of this feature is to provide a means to smoothly ramp the amplitude of the playback data up or down while a test is running.

Accuracy and Resolution

The accuracy with which the original signals are reconstructed from sampled data depends on many factors, some of which are difficult to quantify in a general way. For example, the signal itself is arbitrary in the sense that the waveshapes are unknown in general. The topic of sampling and reconstruction is treated theoretically in many texts on the subject. You are referred to these for further information.

Playback data is presented as 16-bit binary numbers. After interpolation, all data is treated as 32-bit numbers to preserve the resolution of the input data, unless amplitude scaling truncates the data due to an excessively small scale factor. This will occur if the amplitude scale factor is less than 2^{-16}.

Constant Amplitude Control

Constant Amplitude Control is an outer loop control function that controls the cyclic feedback amplitude being applied to a specimen to a desired level in the current control mode by manipulating the cyclic command amplitude. It is useful for extending the usable range of the testing system and is most commonly used with higher frequency sinusoidal loading. For example, with Constant Amplitude disabled, a Load waveform amplitude of 10 kN at 20 Hz for a particular system and specimen might result in a feedback amplitude of only 9kN. By enabling Constant Amplitude, the controller will increase the actual running command amplitude until the feedback amplitude reaches 10 kN. This increase is hidden from the user by the Waveform Generator because it always reports the waveform amplitude parameter to be the value set by the user. However, if the command waveform were displayed on a scope, the increase in amplitude would be observable.

How Constant Amplitude Works

The Constant Amplitude algorithm uses closed loop integral control. A block diagram of the loop is shown in Figure 3-17. The dashed line encloses the functions which constitute the Constant Amplitude Controller. The waveform amplitude set by the user, i.e. the target amplitude, is the command setpoint for the loop. The measured cyclic amplitude is the feedback to the loop. This value is output once per cycle by the amplitude detector on the first sample period of each cycle. The value is one-half the difference between the largest maximum peak and the smallest minimum peak (arithmetically) which oc-

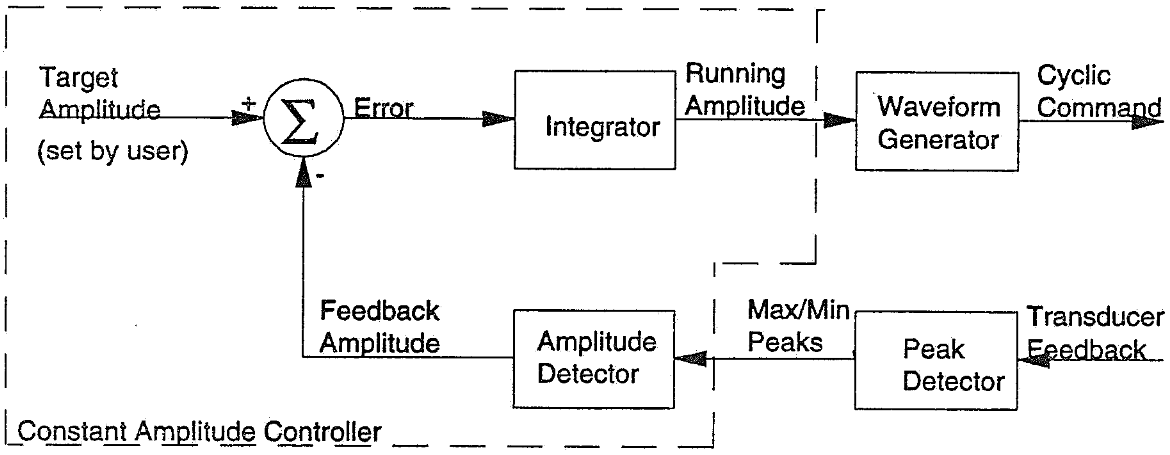


Figure 3-17. Constant Amplitude Controller

curred during the previous cycle. The maximum and minimum peaks are determined by the peak detector which resides in the Sensor Conditioner.

On this same sample period, the error is calculated and integrated to find the new running amplitude which immediately becomes active. The integrator output is calculated as:

$$Running\ Amplitude = Running\ Amplitude + (K \cdot Error)$$

where K is the integral gain. The Waveform Generator uses the running amplitude to calculate the cyclic command for the PID Loop Controller. When Constant Amplitude is enabled, the running amplitude is updated once per cycle.

Performance

Constant Amplitude Control performs best for specimens that have fairly linear loading curves. For specimens with very non-linear loading curves, the amplitude will be controlled accurately, but the mean level and/or peaks of the waveform may be different than expected, based on the static setpoint and the amplitude. The specimen non-linearity introduces the need for asymmetrical over-commanding which early versions of the Constant Amplitude Controller could not handle. Later versions of firmware have outer loop Setpoint Control to handle this situation (more on Setpoint Control later in this chapter).

The actual amplitude achievable by a given testing system is determined by the performance envelope for that instrument. The Constant Amplitude Controller can reliably control to any feedback amplitude which is within this envelope. If the target amplitude is set outside the envelope, unreliable control will result. Under these conditions, the actuator performance is limited by either slew or acceleration. Not only will the desired amplitude never be reached, but the mean level of the waveform will drift because the actuator is running essentially open loop.

Special consideration must be given to the case of running Constant Amplitude Control when using a haversine waveform. In this case, when Constant Amplitude Control is enabled, an apparent shift of the mean level occurs, even if the waveform is within the performance envelope of the system and the specimen is linear. This shift results because a haversine is really a sine wave with a static offset. Specifically, the haversine command function is:

$$y(t) = C + \frac{A}{2} + \left(\frac{A}{2}\right) \cdot sine\left(\omega t - \frac{\pi}{2}\right)$$

where C is the setpoint and A is the haversine running amplitude. The feedback generated by this command will have the same constant terms, because the low frequency gain of the loop is very high. However, the dynamic term will be altered in amplitude and phase. Since phase is not important here, the feedback can be expressed simply as:

$$f(t) = C + \frac{A}{2} + \left(\frac{B}{2}\right) \cdot sine\,(\omega t)$$

The Constant Amplitude Controller responds to the peak-to-peak value of the feedback waveform, B, by adjusting the running command amplitude, A, until B is equal to the target amplitude. A given delta change in A results in a mean level shift of the feedback by half that delta. The result is that the desired amplitude is achieved, but at the expense of shifting the mean of the waveform.

Constant Setpoint Control

Constant Setpoint Control works in conjunction with Constant Amplitude Control to minimize apparent shifts in actual Setpoint of the controlled feedback signal. These changes are particularly noticeable with haver function waveforms running at high frequencies where there is significant rolloff of waveform amplitude. In these cases, due to the rolloff, the waveform minimum peak (or maximum for negative amplitude) drifts away from the commanded Setpoint value.

In functional block diagram form, the Constant Setpoint Controller is very similar to the Constant Amplitude Controller. Figure 3-18 shows how the target Setpoint is summed with the controlling feedback and integrated to become the controlling Setpoint.

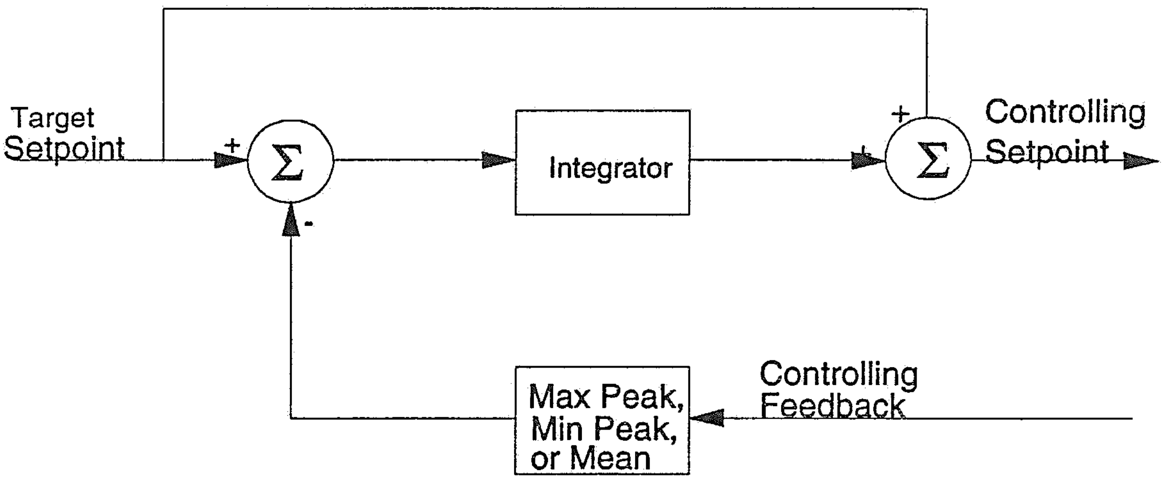


Figure 3-18. Constant Setpoint Control Block Diagram

Constant Setpoint Control works by comparing, once every complete cycle, the target Setpoint value with either the minimum peak (for positive haver functions), the maximum peak (for negative haver functions), or the mean (for normal cyclic waveforms) of the current controlling channel. The result of this comparison is an error that is integrated to generate a correction factor that is then summed with the target Set Point, becoming the actual Controlling Setpoint portion of the loop demand signal. As time elapses, the Constant Setpoint loop reaches equilibrium, with the error approaching zero.

The error integrator state is reset to zero whenever the Waveform Generator switches out of the running state, to eliminate the possibility of sudden changes in actuator position.

Chapter 4
Feedback Processing

Outline

- Transcducer Recognition . . . . Page 4-2
- Calibration Process . . . . Page 4-5
- Auto-Ranging. . . . . Page 4-9
- Using Zero Suppression. . . . . Page 4-11
- Peak Detection Algorithm . . . . Page 4-16
- Saturation Detection. . . . . Page 4-18
- Derived Feedback . . . . Page 4-19

We have seen that, in a typical servo system, there are three main signals that control the system: the command signal that drives the system, the feedback signal that is the result of the command signal, and the error signal that is the difference between the command and the feedback. In this chapter, we will look at the feedback signal and some of the factors that affect it. We will examine the signal as produced by the transducer and describe how the system recognizes and calibrates the transducer. We will also discuss ranging, both automatic and manual, zero suppression, and peak and saturation detection.

Transducer Recognition

All transducers used with the Model 8500 System, including load cells, actuator LVDTs, extensometers, accelerometers, and similar devices, fall into one of two general categories. They are either Instron standard transducers or user-supplied transducers The system will recognize any load cell, extensometer, accelerometer, or other device, even those from other manufacturers, provided that they have been modified with recognition resistors. Devices in this category, including older Instron transducers that did not originally have recognition resistors, are considered "user" transducers, and are given appropriate recognition resistor values.

The purpose of Transducer Recognition is to provide a simple method for detection of the presence of a transducer (and implicitly, the integrity of its connecting cabling), a means to recognize each unique transducer, and to provide operating parameter information about the transducer to the system.

The ultimate goal of transducer recognition is for the system to know which transducer has been connected to the system so that it can select the appropriate coarse gain in the Sensor Conditioner, and to select the proper excitation voltage for the transducer. The Coarse Gain function is shown on the block diagram in Figure 2-4, and is described in the Section "Low Level Inputs" on page 2-14. Coarse Gain is selected by the firmware in response to transducer recognition, and acts to ensure that the system is set for the appropriate sensitivity, and for maximum resolution of the Analog-to-Digital Converters.

To accomplish the recognition task, each transducer has a set of recognition code resistors mounted in its electrical connector. These resistors are chosen to give each transducer its own unique identification. Table A-2 in Appendix A of this manual lists the many different combinations of resistor values, while the associated text in the appendix describes how to select these resistors.

Whenever the Model 8500 powers up or when a transducer or sensor is plugged into the system, the system looks at the code resistance it finds for that transducer, then closes the calibration relay and reads the resistance again. If it finds that the two values are the same, the system assumes that the transducer is an Instron transducer, and goes to a look-up table for parameters to set up the system. If it finds that the first value is zero and the second value is some finite resistance, this indicates that the transducer is a “user” transducer. The system then uses the value of the second resistance to find out how to set up the system (assuming its parameters have been stored previously). If the second value is very large, the system assumes that there is no transducer connected.

For each recognized transducer, there is a set of six parameters associated with that particular transducer. The first three of these, considered “hard” parameters because they are fixed and cannot be changed by the user, are Coarse Gain, Transducer Excitation, and Calibration Type (Electrical or Manual Calibration). The second set of three are “soft” parameters because they carry user-assignable values. These parameters are Full Scale, Transducer Units, and Channel Label (Position, Load, Strain, Acceleration, or whatever name you wish to as-sign). When a standard Instron transducer is being used, all six parameters are known and defined, but with user transducers, the hard parameters must be selected from Table A-2, and the soft parameters defined by the user.

Calibration Process

The calibration process in the Model 8500 is very flexible to take into account the many types of transducers that may be connected to the system. Calibration can be fully automatic when initiated by the operator, it can be a manual process performed by the operator, or it can be a process whereby previously stored calibration parameters can be recalled and made active. In addition, a "spot-check" electrical calibration can be performed to ensure the validity of the current calibration numbers.

Fundamentally, calibration of the transducer feedback signal is a three-step process for whichever calibration method is used, and holds true for all modes of system control. First, a coarse balance is performed in which the transducer feedback signal is set to zero. Then, a span adjustment is made that relates to a known physical value. Finally, a fine balance is performed to trim out slight imbalances that occur from the span adjustment.

These steps must be performed in this sequence in order for the calibration to be valid. If the process is interrupted for any reason, you must repeat the interrupted step, then continue.

Manual Calibration

Manual calibration of the system requires that the operator perform the three steps of the calibration process from the Front Panel or over the GPIB Interface Bus.

1) Coarse Balance: The transducer is set to the desired engineering zero point. The Sensor Conditioner performs an iterative procedure to set the balance stage

to achieve the smallest possible signal. A maximum of 25% of full scale may be balanced. If the input signal is larger, the coarse balance step will fail.

2) Span: The transducer is set to a known physical value, using an independent load cell standard, extensometer calibrator, or other appropriate independent standard. This value is defined to the Model 8500 before the "calibrate span" command is sent. For user transducers, the full scale of the transducer must be defined before the physical value can be set properly. The sensor performs an iterative procedure to set the span stage to yield a signal as close as possible to the desired physical value. An iterative cross-calibration of the balance stage is performed by backing off the signal 1/2 full scale from the physical value. This calibration is needed for accurate zero suppression of the signal after the full calibration sequence is complete. Data is taken after each procedure for use in subsequent software correction calculations.

3) Fine Balance: The transducer is again set back to the zero point. The Sensor Conditioner performs another iterative balance to achieve the best balance stage setting, and then measures the balance residue on each range. Software correction factors are calculated for span and balance using this data and the data collected during the span calibration. Again, a maximum balance of 25% of full scale is allowed.

Electrical Span Calibration

The preceding calibration procedure is referred to as a "manual" calibration process, and provides a complete calibration of each transducer. An Electrical Span Calibration provides an alternate means of producing the span calibration point. In this case, a known precision resistance is connected across the transducer's strain gauge bridge, producing a calibrated transducer output voltage.

The connection of the precision resistance is controlled through the calibration relay. The relay can be controlled from either the Front Panel or the GPIB, and the calibration relay can only be activated on a channel when that channel is not in control of the system. This is because the calibration resistance connected across the strain gauge bridge unbalances the bridge, and could cause uncontrolled and unexpected actuator motion.

Auto Calibration

In Auto Calibration, the three steps described above are performed automatically by the system. The Span calibration step uses the Electrical Span Calibration of step 2) above, automatically closing the calibration relay. This is true for all Instron transducers; for "user" transducers, you must insert your own resistance for the Span signal value for your transducer (see the Section "Transducer Recognition" on page 4-3 and Appendix A of this manual).

Rebalancing

Rebalancing of the transducer can be performed at any time *after the transducer has been calibrated.* Rebalancing may be required, for example, if you change to a different set of grips with a different weight on the load cell, or after you have pulled out the gauge length pin on an extensometer prior to running the test. Rebalancing is the same as the Fine Balance step in the calibration process above, except that the software correction factor is not recalibrated.

Restoring Stored Values

When the Model 8500 System is powered down at the end of the day, or if a transducer is unplugged from the system while it is running, current calibration information is automatically saved. This same calibration data will be restored when the system is next powered up, or if the same transducer is replugged into the system. However, if a new transducer is plugged into the system, the stored calibration data is permanently lost and cannot be recovered. In this case, the new transducer must be recalibrated.

During the Restore Calibration Data process, the Position Channel will be restarted in the fully calibrated state. For all other channels (load, strain, etc.), the calibration data is restored, but the channel is not calibrated unless the operator elects to restore the calibration data. In this case, the green CAL light will be lit steadily immediately.

Auto-Ranging

Realtime Automatic Ranging

With Auto Ranging, operator interaction with setting the ranges of the system is eliminated. The range never need be selected explicitly on any channel, just left in Auto Range at all times. The digital data will have full 19-bit resolution within ± 10% of the transducer full scale from the zero suppression point. The operator only needs to set the zero suppression point somewhere near the region of the data that requires the most resolution. If the signal moves farther than ± 10 % from this point, no data is lost, the data just gradually sheds resolution to the 16-bit level afforded by the converter at the times 1 range. Over-ranging will never occur unless the test exceeds the physical limits of the transducer or the data moves farther than ± 109% of full scale from the zero suppression point.

How Auto-Ranging Works

The ultimate goal of Auto-Ranging is to obtain the maximum possible resolution for each data sample without ever losing a single data point by being on too sensitive a range and over-ranging the converter. With Auto-Ranging, the processor examines each A/D reading in realtime at the 5 kHz sampling rate, and sets the range for the next reading. The selection of range is based on an algorithm which uses a three-tiered decision-making process that is based, in turn, on both the static level of the signal and the rate of change of the signal. The algorithm maximizes data resolution for slowly-moving monotonic signals. For cyclic signals, the algorithm maximizes resolution for the cyclic amplitude. To avoid ever losing data, the most sensitive range is selected so that the maximum slew rate of the signal cannot overrange the converter in less than one sample period, (200 μsec). This corresponds to the times 8 range for a Model 8500 Servohydraulic system, and the times 16 range on a Model 8560 Electric Actuator system (due to decreased signal bandwidth).

Using Zero Suppression

Zero Suppression in the Model 8500 is a technique used to shift the absolute zero (electrical zero reference) of the feedback waveform signal with reference to the physical zero reference. You might want to do this, for example, when you apply a preload to a specimen, then cycle above and below this preload. You would then suppress the value of the preload, in effect moving the system physical zero to the electrical zero of the cyclic waveform. In some cases, this could allow the system to select a more sensitive range for better data resolution.

You can specify an amount to be suppressed directly in engineering units and manually turn the suppression on and off. In addition, the Position Channel offers the unique feature of suppression while in control on that channel, which is particularly useful during test setup.

Zero Suppression Described

Zero Suppression is a local function of the Sensor Conditioner, meaning that the effects of Zero Suppression are normalized locally on the sensor before the data is passed on to other modules within the system. Suppression of the signal is performed by the microprocessor by manipulating the Balance Digital-to-Analog Converter (DAC) to provide an electrical offset of the physical zero of the transducer. This means that when the transducer is at physical zero, a non-zero signal is seen at the balance stage of the conditioner electronics. Conversely, if the transducer is at a non-zero point, suppressing the signal to zero means the electrical signal is zero after the balance stage. The importance of Zero Suppression is that auto ranging (and manual ranging) of the signal is centered about the electrical zero of the signal. The electrical zero is the point about which the A/D Converter resolution is maximized by the use of ranging. Thus, suppression allows you to place the point of maximum data resolution at any point of the transducer physical range.

The firmware keeps track of the offset between the electrical and physical zeroes and applies this offset to the digitized data before storing and broadcasting it for use by other data manipulation algorithms, either local or external. Hence, the digital data that is produced by the sensor, and thus the Model 8500 Tower, is always in the same format relative to the transducer physical range regardless of whether the signal is suppressed or not. This is a particularly important point for programming the Model 8500 from the GPIB. All the data values in the GPIB Command Set are independent of the suppression status, including the data read back from the data logging. It is equally important to note that the Front Panel data does depend on the state of Zero Suppression. The Front Panel locally applies the suppression offset to data relevant to a channel with suppression on before displaying it to the user. A delta symbol (Δ) is placed in front of the units for such data to indicate that the data has been modified.

Consider, as an example, a system with a 100 kN load cell and a specimen loaded to 20 kN in load control. The Load Suppression value is set to 10 kN. With Suppression off, the Front Panel live data and Load Command Set Point would both read 20 kN. The same values read from the GPIB would both be 0.2, as the format is a fraction of full scale. If Suppression were on, then the Front

Panel would adjust both the live data and Set Point value to read 10 kN (20 kN actual minus 10 kN suppressed), whereas the GPIB values would still read 0.2.

Methods of Zero Suppression

In order for the sensor conditioner firmware to properly normalize the data after suppression is applied, the amount of electrical suppression must be known and must be calibrated into physical units. The two different methods for doing this are reflected in the two modes of using Zero Suppression. The first method, called Pre-calibrated Suppression, entails setting the suppression level manually to the desired setting and then turning the Suppression State to on. This type of suppression uses a calibration of the Balance DAC hardware versus physical units which is measured automatically during the transducer calibration process. The firmware uses this calibration to calculate the nearest value of the Balance DAC which would bring the electrical signal to zero if the transducer were physically at the specified suppression level. A correction term is also calculated to account for the step size of the DAC. The value is then written to the DAC and the correction and suppression levels applied to the digitized data and suppression is complete. The Balance DAC calibration is not as accurate as the actual transducer calibration. Hence, small errors in the data may result. Continuing the example above, if Suppression were turned on using pre-calibrated suppression, the resulting Front Panel data might read 10.05 kN and the GPIB data might read 0.201. Note that this error is only a zero error and not a span error - signal changes relative to the suppression point are accurate to normal system specifications. This type of suppression is very useful if the suppression level desired is not the current level of the signal or if the signal is not static.

The second method of suppression is called Suppress Current Level. This method is invoked directly from the Front Panel or GPIB Command, and the sensor then performs an automated sequence of steps. The first step is to take an averaged reading of the signal to get a very precise value for the current level. The signal must be absolutely stable to get a good reading. If it is not, the sensor will abort the suppression sequence with an error. After establishing the current signal level, the sensor performs an iterative procedure using the Balance DAC to get the electrical signal as close as possible to zero. Again, a precise reading is taken, this time of the error from zero, which is then used as a software correction factor to bring the digital data to exactly zero. Finally, the original level is added back into the digital signal, and the suppression sequence is finished. The sensor produces data which meets the accuracy specifications of the system both for zero and span. Note that the signal must be absolutely stable during the entire process and that the resulting suppression level is always the current level as measured at the start of the suppression sequence.

For both methods of suppression, the Balance DAC value is changed and the balance stage must settle. During this time, the data produced by that sensor will be invalid. For this reason, changes to the suppression state are locked out if you have any Event Detectors or Limits active on that channel - these functions require valid data. The same holds for the channel which is in control, or armed as the next mode of control.

The exception to this last rule is the Position Channel. As a special case, suppression of the Position Channel in

Position control is allowed. This is accomplished by freezing the valve drive, which essentially opens the control loop, throughout the time period when the data is invalid. If the servovalve drive is perfectly balanced, then the actuator motion will be well less than 0.001 inches over the course of the few seconds or less that are required. The servovalve balance accuracy is critical. In order to achieve this, the Integral Loop Gain must be non-zero, and the system must have been completely static (no actuator movement) for 3 to 5 integrator time constants (the reciprocal of the integral gain gives the time constant in seconds). The smaller the integral gain value the better the valve balance but the longer the waiting period for static equilibrium. A value of 0.5 should give acceptable results, with a corresponding waiting period of 10 seconds for static equilibrium. Also, the system must be set up to properly hold a stable set level, without integral oscillations, by having appropriate loop gain and dither settings.

For more information on zero suppression and the computer, see the Model 8500 GPIB Interface manual for the following:

Refer to GPIB Message Header number 117 for Zero Suppression level parameter.

Refer to GPIB Message Header number 116 for Zero Suppression manual state control

Refer to GPIB Message Header number 118 for suppressing current level to zero action.

Peak Detection Algorithm

The Model 8500 Peak Detection module resides on the Sensor Conditioner. The basic detection algorithm runs at the 5 kHz conversion rate. The actual occurrence of a peak is reported to the 1 kHz module which handles storage and broadcasting of peak values, and calculation, storage, and broadcasting of cyclic values, and interfaces to Data Logging, Event Detector, and background usage of this data.

The Peak Detection algorithm is a simple turning point algorithm with a selectable hysteresis value, referred to as the noise sensitivity factor. The algorithm looks alternately for maximum and minimum peaks. The current slope of the signal is defined based on the last peak encountered - a minimum last peak means a positive slope for the signal, a maximum means a negative slope. Each new data sample is checked against the previous potential new peak. If the new sample continues along the same slope as defined above, then it is declared the new potential peak. If the sample shows a change in slope, then the reversal magnitude is calculated as the absolute value of the difference between the new sample and the previous potential peak. The reversal is checked against the noise sensitivity factor. If the reversal is smaller, then no action is taken. If the reversal is larger, then a new peak is declared. The current potential peak value is copied into the last peak and tagged appropriately as a minimum or maximum. The algorithm reverses its target slope and begins looking for the opposite peak.

The declaration of a new peak value triggers the 1 kHz processing loop to store and broadcast the peak value to the appropriate maximum or minimum internal database location and token slot respectively. The current amplitude and mean values are recalculated as:

$$Amplitude = \frac{(Maximum\ Peak - MinimumPeak)}{2}$$

$$Mean = \frac{(Maximum\ Peak + MinimumPeak)}{2}$$

These values are also stored to internal database locations and broadcast to token slots.

The default value for noise sensitivity is measured automatically during the final balance step of the calibration sequence. Fifty data samples are measured using the most sensitive range (x128) and a simple peak-to-peak noise value determined. The noise sensitivity is set to 10 times this peak-to-peak noise. You can set the value differently via a GPIB command to customize the algorithm to particular testing applications. This adjustment is also available from the Front Panel.

The accuracy of the Peak Detector depends on the accuracy of the transducer input signal, the noise on the signal, and the frequency of the signal. In the best case, the Peak Detector accuracy matches that of the signal. In the worst case, the Peak Detector adds a percentage uncertainty due to sampling. The worst case is for the "sharpest" peak, i.e., a peak in a waveform with maximum frequency. For a 100 Hz waveform, the Peak Detector has 50 sample points per cycle, resulting in a 0.2% of reading in the peak value. For a 50 Hz waveform, or 100 samples per cycle, the uncertainty is only 0.05% of reading.

Refer to GPIB message header number 120 in the Model 8500 GPIB Interface manual for noise sensitivity setting.

Saturation Detection

Saturation Detection is a feature in which the Sensor Conditioner detects an overflow condition of either the electrical or the physical signal from the transducer. Saturation can occur for two reasons. The first is when the A/D Converter overflows due to an inappropriately selected manual range (this cannot happen with Auto Ranging), or an electrical fault such as a broken or disconnected transducer cable. The second is when the transducer signal exceeds 135% of full scale. In both cases, the Sensor Conditioner declares to the system that data from this transducer is no longer valid. If this channel is being used for system control, then the system hydraulics are shut down. In addition, the following actions are taken by the Sensor Conditioner:

- All Event Detectors are set to the OFF state.
- If the Limit in the direction of the saturation is armed, then the Limit trips and the Limit Actions will be taken normally. The maximum Limit trips if the signal saturates positively, while the minimum Limit trips if the signal saturates negatively.
- If Transducer Protection is enabled for this transducer, then the system hydraulics are shut down. Load cells have transducer overrange protection enabled automatically. Other types of transducers will only be protected if the user enables it from the GPIB Interface.

Derived Feedback

Derived feedback is a term used to describe a signal mathematically generated by combining real feedback signals and performing some calculation on them. The calculation is done at the same rate at which the feedback is sampled, so the result can be used as an additional channel of control, an additional command, or a compensation signal. The Cross-Compensation feature that is standard in the Model 8500 is an example of derived feedback; in this case, a linear combination of two feedback signals to form a third one.

Derived Stress and Strain

Servohydraulic testing systems, in general, have used a form of strain measurement known as *Engineering Strain*, or simply *strain*, which is expressed as:

$$\frac{elongation}{original\ gauge\ length},$$

where the original gauge length is a constant.

True Strain, on the other hand is expressed as:

$$\frac{elongation}{total\ length}.$$

The difference between the two is that in True Strain, the total length of the specimen is constantly changing as the test proceeds. Most materials testing systems cannot accommodate a changing gauge length, and thus operate in what is basically elongation control, which is really just position control within the gauge length of the specimen.

True Strain

True Strain is mathematically related to Engineering Strain by the equation:

$$\text{True Strain} = \ln(1 + \text{Engineering Strain})$$

The Model 8500 Plus system offers a mode of operation that allows you to generate waveforms and set event detectors based on True Strain. In this mode, the control variable is elongation, but the command is compensated exponentially to follow a true strain profile in real time. The resultant feedback signal is then converted into True Strain by the above equation, and used as an input to event detectors on the Strain channel.

True Stress

True Stress is a "derived" mode for the Load channel in the Model 8500 Plus. *True Stress* is defined as:

$$\frac{load}{\text{current } cross\text{–}sectional\ area},$$

while *Engineering Stress* is defined as:

$$\frac{load}{\text{original } cross\text{–}sectional\ area}.$$

The estimate of current or instantaneous cross-sectional area is based upon a calculation which uses the instantaneous *Engineering Strain* values, and assumes that the volume of specimen material is constant in the plastic region:

$$\sigma = \mathit{Engineering\ Stress} \times (1 + \mathit{Engineering\ Strain})$$

where σ is the True Stress.

The operation of the True Stress mode is similar to that of the True Strain mode in that the actual control loop is based upon the load variable, but the command is compensated by the calculated area to create a loading profile based on true stress. The resultant load feedback signal is then converted into true stress by the above equation, and used as an input to the event detectors on the Load channel.

The technique of compensating the command, rather than the feedback, in a nonlinear way to achieve a function of true stress or true strain prevents the control loop from "seeing" the nonlinearity. Because of this, the loop shaping parameters are not affected, and adaptive control is not affected in any way by the fact that true stress or true strain modes are active.

Chapter 5

Closing the Loop

Outline

- Introduction . . . . Page 5-2
- The Loop Controller . . . . Page 5-4
- Loop Shaping . . . . Page 5-11

Loop Shaping is the process whereby the overall gain of the system to a command input is adjusted to provide optimum response. This chapter describes the Model 8500 Loop Controller and how it works, then describes the Loop Shaping process. It further describes how Loop Shaping and Auto Tuning are related to Adaptive Control.

Introduction

The third element in a servo system is the Loop Controller which generates the servovalve drive signal. This signal is based on the error signal, which is the difference between the command signal and the feedback signal that were discussed in the previous two chapters. In this chapter, we will describe the error signal processing that takes place in the Model 8500, and explain how this processing "closes the loop".

The Closed Loop Control function is a part of the Master Dynamic Controller (see Figure 2-3). Inputs to the Loop Controller are the Command and Feedback signals described in Chapters 3 and 4. Within the Loop Controller, the Command and Feedback are compared, and an Error signal is calculated from the difference between the two input signals, as shown in Figure 5-1. The Loop Controller applies a series of calculations to this error signal to produce a drive signal to optimize the system response. This drive signal is then sent to the servovalve.

In the Model 8500 Controller, the four terms are arranged in a cascade structure. The first stage (Derivative Stage) produces an output that is equal to the error plus a term proportional to the derivative of the error. The second stage simply scales the first stage output by a constant (Proportional or P term). The third (Integrator Stage) outputs a term that is equal to the integral of the second stage output summed with the second stage output itself. The fourth and final stage (Lag stage) attenuates high frequency components in the third stage output signal. In introduces phase lag and does the opposite of the first stage, which provides phase lead.

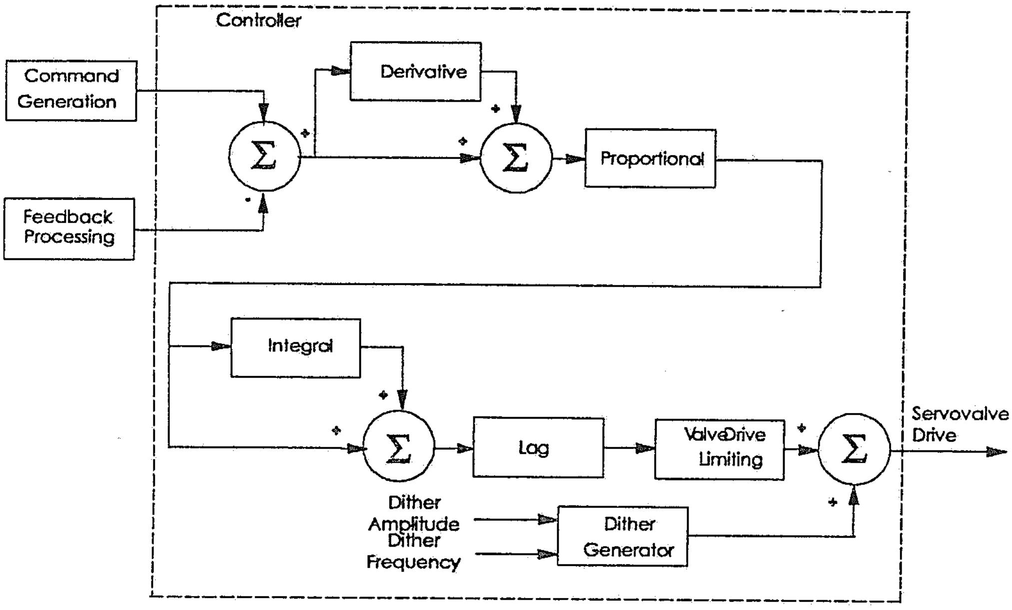


Figure 5-1. Loop Control Block Diagram

The Loop Controller

Description

The Model 8500 Loop Controller is a four term PIDL controller. In this type of controller, the controlling error is processed in four ways that are combined to form the control (servovalve) drive signal.

Normally, only the P I and D terms are adjusted, with L set to zero: Proportional Gain, which represents the ratio of the control signal (servovalve drive) to the error signal, expressed in dB; Integral Gain, which controls the rate at which the control error is integrated with respect to time and is therefore expressed in units of 1/second; Derivative Gain, which defines a control term that varies with the rate of change of the control error, expressed in seconds; and Lag Gain, also expressed in seconds, which reduces the gain at higher frequencies.

Proportional scaling of the error causes actuator velocity to track the instantaneous loop error in the direction that reduces the error. This is the basic mechanism of negative feedback control.

Integral Gain provides adjustment for loop offset and long-term drift in electronic control circuits and the servovalve.

Derivative Gain is used to optimize system response after Proportional Gain has been set.

Lag Gain is used to damp out mechanical resonances which fall inside the control loop bandwidth.

The L or Lag term is only needed when the testing system contains a component with a lightly damped, low-frequency resonance, such as a long-arm extensometer. In this case, the D term should be set to zero and Lag used instead of D to provide damping.

These four terms are often referred to as the PIDL parameters. Separate copies of the PIDL parameters are maintained for each mode of control. When a mode transfer occurs, the appropriate set of parameters is automatically selected. In addition, the controller error at the moment of transfer is guaranteed to be zero through the adjustment of the loop command to equal the instantaneous feedback in the new mode of control.

Proportional Gain

The Proportional term generates a component of the total drive that is directly proportional to the error. In the Model 8500, the constant of proportionality is expressed in units of dB, where 0 dB corresponds to a factor of 1.

The constant of proportionality (Proportional Gain) controls the rate at which the loop is able to change when the command changes. When the command is static (not changing, as when no waveform is being generated), the error will normally reach a steady state equilibrium of zero. This is because a non-zero error would result in actuator motion.

However, this is true only if the servovalve is perfectly balanced, there are no offsets in the analog electronics driving the valve, and there is no static actuator loading (non-zero mean load on a specimen, or a specimen preload). Specimen load, varying ambient temperatures in the control circuits, and a varying hydraulic fluid temperature can cause the offsets in the error signal.

Integral Gain

The Integral term generates a component of the drive signal equal to the integral over time of the error, scaled by a constant. The constant is expressed in units of inverse time, that is, 1/second. This constant is sometimes referred to in units of repeats per second, meaning that a constant error will cause the integrator to change so that it appears that after one second, the error has been added a number of times equal to the constant. For example, if the integrator constant is set to 2 repeats per second and the error is such that when scaled by proportional gain, valve drive would be 10 percent of full scale. Then, after one second, the drive will increase by an additional 20 percent, and after two seconds it will have further increased by 20 percent, *etc.*

Adding the Integral term to the Proportional term corrects for the static error described above. When the command is static and the integration constant is non-zero, the loop will reach a static equilibrium with zero controlling error, even in the presence of static loads. The rate at which this is achieved is determined by the value of the integral time constant.

In addition to the integrator operation described above, the state of the Integrator is affected by certain events. When saturation is detected at any stage of the PID process, the integrator is automatically turned off to avoid the phenomenon of windup. Once the saturated condition is cleared, the integrator is turned back on. The integrator is also turned off automatically when the actuator is disabled to prevent the possibility of integrator windup.

When switching between low and high actuator pressure, the value of the integrator is changed. When the transition from high to low pressure is detected, the state of the integrator is saved in memory. While the system is at low pressure, it is likely that there will be a rather large integrator buildup compensating for the large load-related static valve drive required to reach zero controlling error. At the transition back to high pressure, the integrator is reset to the value previously saved in memory. This feature eliminates the potential actuator bump that would otherwise occur.

Derivative Gain

The Derivative term generates a component of the drive signal equal to the time rate of change of the loop error, scaled by a constant. The constant has units of milliseconds. You can think of the effect this term has by considering the following example. The error is changing at a rate that causes the drive, when scaled by the Proportional term, to change at a rate of 10 percent of full scale per millisecond. Then, if the Derivative term is set to 0.5 milliseconds, it will add another 5 percent of full scale to the servovalve drive signal.

Derivative action provides damping within the control loop. This allows the Proportional Gain to be set higher than is possible without Derivative Gain.

Lag Term

In addition to the three PID terms, the servohydraulic controller incorporates a Lag term in its loop shaping algorithm. This introduces a first-order lag into the control error path, and the time constant of the lag, in milliseconds, can be adjusted directly from the Front Panel. The Lag term is not adjusted automatically by the control loop, and for most applications, can be left in its default setting of 0.0 ms, where it will have no effect.

The Lag term is used to counteract the effects of resonances in the system. A typical example would be in strain control on a high temperature system where it is difficult to avoid using an extensometer with long arms, having a resonant frequency within the bandwidth of the testing system. If incorrect, this resonance will force the use of a low control loop gain, and this will lead to low bandwidth for dynamic test, and poor resolution and hysteresis in static testing.

By increasing the Lag time, it is possible to suppress the effects of this resonance on the control loop. The optimum setting is a compromise between suppressing the resonance and retaining the required bandwidth for the test. As well as extensometer resonances, the Lag term can be used to counteract the resonances due to large masses (grips) on small actuators, and with load frame resonances in structural test rigs.

When Lag is needed, the optimum setting for the Lag term can best be found by driving the loop with a small amplitude squarewave, and examining the output waveform on an oscilloscope. The resonant frequency will be seen superimposed on the squarewave, and the Lag term can then be increased until the oscillation due to the resonance is reduced to a negligible level. The PID terms can then be optimized by using Auto-Tuning.

Recommended Lag settings for use when an oscilloscope is unavailable are zero if no resonant problems are experienced, and 30.0 milliseconds when using extensometers which are known to have a low resonant frequency. The setting of 30.0 milliseconds will be higher than necessary in most cases, but will allow stable testing to be carried out. It should be noted that, unlike the use of filters in the feedback, the use of Lag does not modify the feedback signal or introduce phase errors between position, load and strain.

Valve Drive Limiting

The valve drive may be limited to arbitrary maximum and minimum values for the purpose of limiting maximum control hydraulic fluid flow to the actuator. The PID output is continuously compared against maximum and minimum limits. When greater than the maximum limit, the drive is set to maximum, or when less than the minimum limit, is set to the minimum. Whenever the drive is being limited, the Integral Gain is set to zero to prevent Integrator windup.

There are two sets of valve drive limits. One set is active when the actuator is in the Low Pressure state. The low pressure limits are adjusted in conjunction with the manifold shunt valve orifice to control the maximum force that can be generated by the actuator. The high pressure limits are available for particular applications that may want to limit the maximum actuator slew rate.

Dither Generation

A high frequency sinusoidal signal, known as Dither, is added to the valve drive to reduce the effects of friction in the servovalve. The Dither component amplitude and frequency are adjustable from either the Front Panel or the GPIB. The Dither Generator updates at the rate of once every 200 microseconds. Thus, at a Dither frequency of 500 Hertz, there are 10 samples of each cycle of the Dither sine wave generated.

Loop Shaping

Loop Shaping is the process where the response of the control loop in each control mode, as determined by the PIDL settings, is adjusted for optimum dynamic response. Manual Loop Shaping is used to set the four PIDL gain controls for optimum loop response when the operator has the experience to improve on the default settings, or when special test conditions warrant changing the defaults. It requires the use of an oscilloscope, and the procedure is described below.

Auto-Tuning is a form of Automatic Loop Shaping, and is used whenever one of the system's major components, such as the servovalve, the extensometer, the specimen grips, or the load cell are changed. Auto-Tuning, in effect, re-establishes the system's initial commissioning prior to using adaptive control. Auto-Tuning is described below.

The overall servoloop response must be optimized to allow for the type of test, the compliance of the specimen, and for any other factors that can affect loop response. Thus, Loop Shaping should be performed for all modes of control which will eventually be used for system control during a test. Loop Shaping in Position control must be done without a specimen, but with the grips installed. In Load control and Strain control, a dummy specimen must be installed for Loop Shaping because the specimen compliance has a significant effect on loop response.

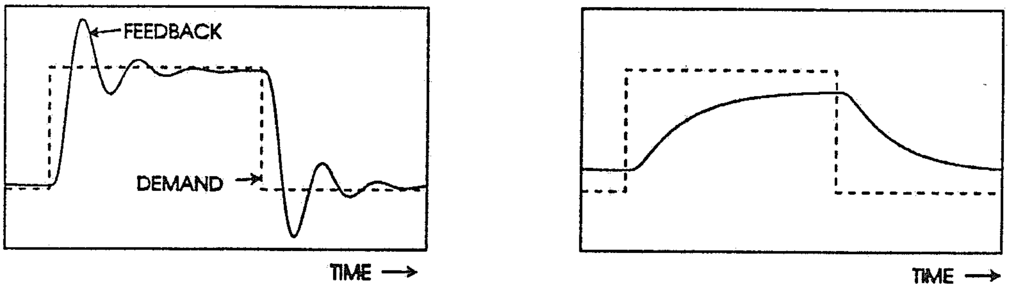
Manual Loop Shaping

In manual Loop Shaping, a square waveform (obtained from the Waveform Generator) is used as the command signal. The resulting feedback waveform is observed with an oscilloscope, and the gain parameters are then adjusted for optimum response. These waveforms, shown in Figure 5-2, can be obtained by connecting an oscilloscope to the Analog Output connectors on the back of the Tower Console. It would not be necessary to view these waveforms if you are doing an Auto Tuning in any channel, because the Loop Shaping gain parameters are computed automatically during Auto Tuning (see the Auto-Tuning Section below). When manual Loop Shaping, however, best results can be obtained by viewing and optimizing these signals.

The action of the gain controls is described in the previous section, but the practical affect of adjusting the PID gain controls is shown in Figure 5-2. Too much Proportional Gain will cause overshoot and ringing on the transient response, while too little Proportional Gain will cause undershoot and rounding, as you can see in the top row of waveforms in the illustration. The second row of two waveforms shows the affects of Derivative Gain, while the third row shows how to set Integral Gain. The combined effects of all gain controls, when adjusted properly, should result in the waveform shown at the bottom of the diagram.

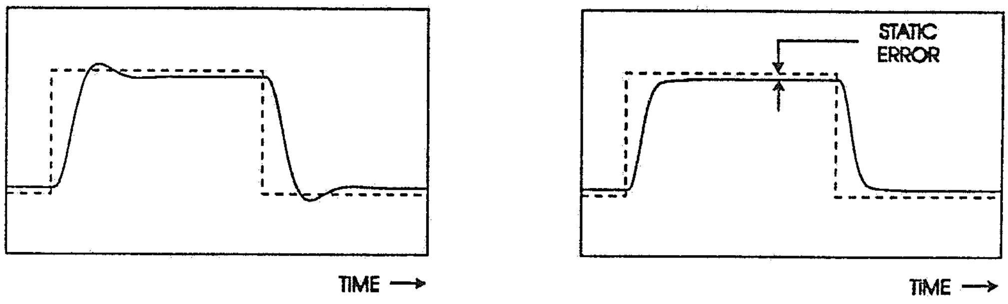
Auto-Tuning

A servo control system that is optimally tuned, or “loop shaped”, gives the smallest tracking error between the command and feedback over the widest range of frequencies. As explained in the above section, manual loop shaping results in the combination of proportional, integral, and derivative gains which produce the best square wave response, as observed on an oscilloscope, for a given set of initial test conditions.



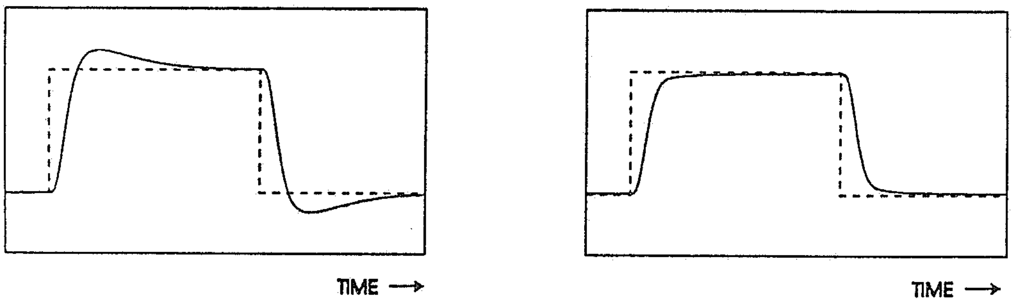
PROPORTIONAL GAIN TOO HIGH

PROPORTIONAL GAIN TOO LOW



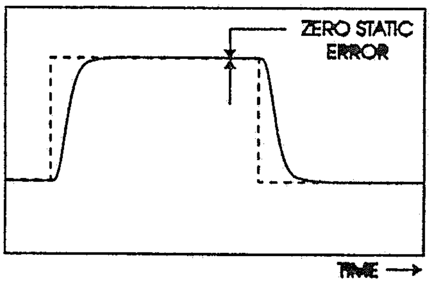
CORRECT PROPORTIONAL GAIN
ADJUST DERIVATIVE GAIN TO
REDUCE OVERSHOOT

CORRECT PROPORTIONAL AND
DERIVATIVE GAIN. ADJUST INTEGRAL
GAIN TO REMOVE STATIC ERROR



INTEGRAL GAIN TOO HIGH

INTEGRAL GAIN TOO LOW



CORRECTLY OPTIMIZED RESPONSE

Figure 5-2. Effects of Loop Shaping Adjustments

Auto-Tuning, on the other hand, is not needed except when one of the system's major components is changed. It re-establishes the start-up parameters necessary for Adaptive Control to work by tuning the loop PID parameters optimally for the current system configuration. Chapter 6 contains a discussion of how and when Adaptive Control and Auto-Tuning would be used.

Auto-Tuning consists of the application of an approximate 30 second burst of small amplitude square wave signals. It is conducted in the current mode of control, *i.e.* position, load, strain 1, or strain 2. Any test setup, including the user's own arrangement, can be used. A specimen should not be installed when tuning in position control, but load control and strain control require a specimen. Strain control must be tuned with the extensometer that will be used for the materials test.

Chapter 6

Adaptive Loop Control

Outline

- Introduction .... Page 6-2
- The Instron Adaptive Controller .... Page 6-6
- Enabling/Disabling Adaptive Control .... Page 6-13
- Summary .... Page 6-14

This chapter describes Adaptive Loop Control, which is a means of controlling loop shaping parameters automatically during the course of a materials test. The chapter illustrates the need for Adaptive Control, describes how it is implemented in the Model 8500 PLUS, and tells how to use it.

Introduction

In the previous chapter we discussed Loop Shaping in the Model 8500, and how the PID parameters are set. In some cases, Loop Shaping is adequate to set the gain of the system for generalized testing, but, since the stiffness of many materials specimens changes during the course of the test, PID parameters set at the beginning of the test may not be correct for later stages of the test. A method of automatically adjusting loop shaping while the test is running would help to overcome this problem.

The Need for Adaptive Control

Adaptive Loop Control is desirable because the dynamic behavior of the servohydraulic testing system is affected by the stiffness of the test specimen. Sensitivity to specimen stiffness poses two problems; first, the system controller has to be retuned every time a different type of test specimen is loaded (currently, such retuning is done manually, and is sometimes not done well), and second, even if the system controller is correctly tuned at the start of a test, stiffness changes during the test prevent optimum performance from being maintained. Such stiffness changes are common, for example, in metals tests where damage mechanisms such as propagation of fatigue cracks or transitions from elastic to plastic behavior cause the stiffness to change. Other specimens, such as elastomeric components, have an inherently non-linear stiffness characteristic.

How a stiffness change affects the testing system depends on the mode of control used for the test. In load control, response becomes more sluggish as the stiffness of the specimen reduces, as shown in Figure 6-1. In the

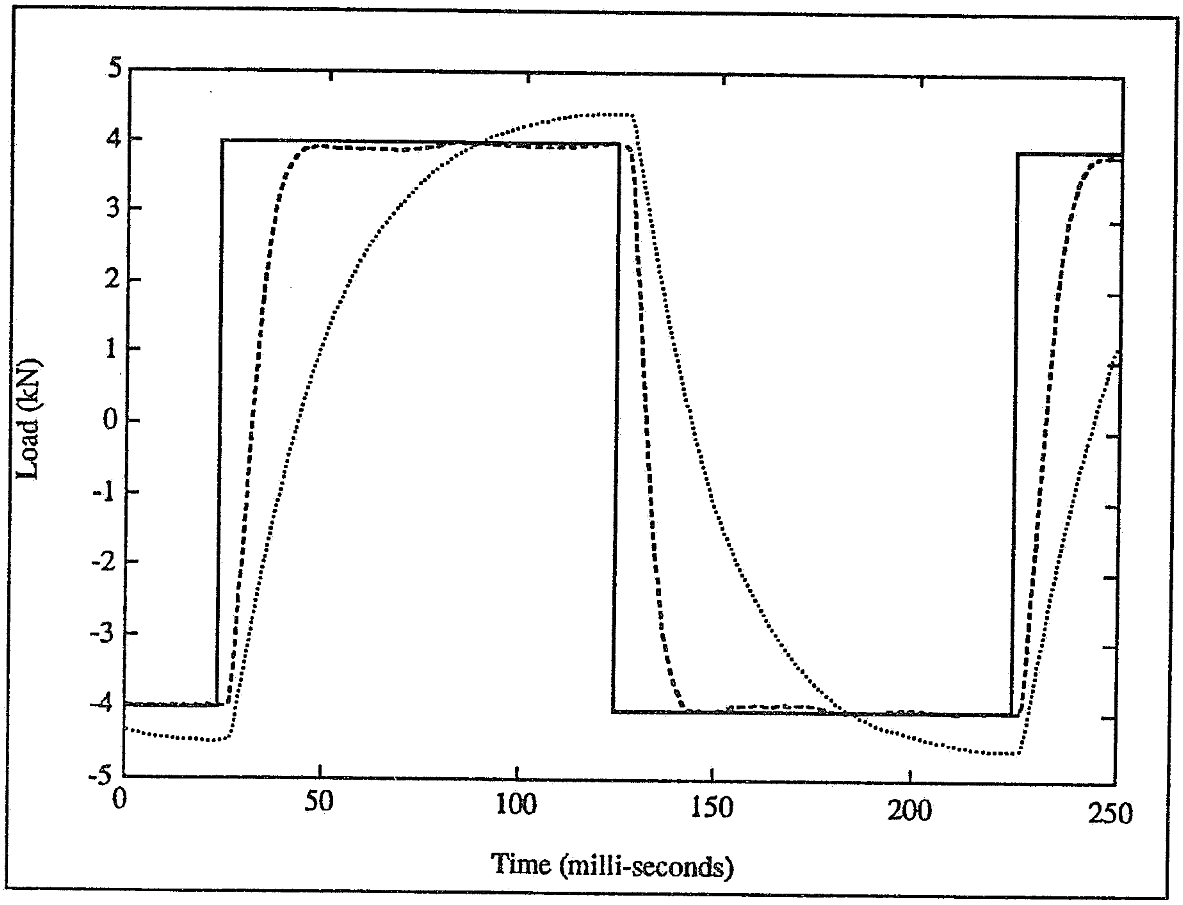


Figure 6-1. Sensitivity to Specimen Stiffness in Load Control

diagram, the command signal, shown in solid line, is a 5 Hz square wave, while the dashed line represents the system response with a stiff specimen. The dotted line represents the system response with a soft specimen, and demonstrates how the change in specimen stiffness can affect the system response.

In strain control, the reverse happens; response becomes sharper, but this can lead to closed-loop instability, as shown in Figure 6-2.

Sensitivity to stiffness change depends on the fixed stiffness of the hydraulic actuator and load frame. The load

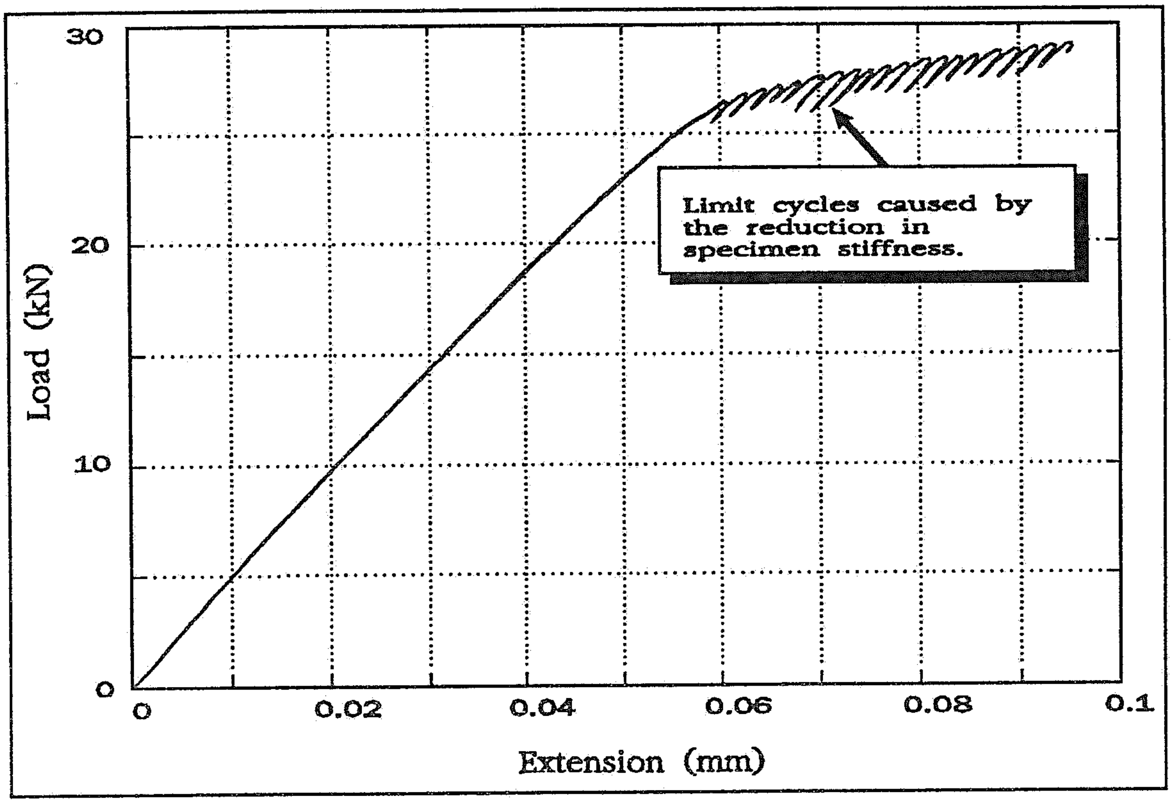


Figure 6-2. Instability in Strain Control at Specimen Yield

frame is stiff to minimize the strain energy stored when the specimen is loaded. Actuators, on the other hand, come in all shapes and sizes to suit varied requirements of speed, force, and stroke. Sensitivity is worst in load control if the actuator is stiff. In strain control, systems fitted with "soft" actuators tend to be most affected.

Advantages of Adaptive Control

A challenging application is low-cycle fatigue testing where the test specimen is repeatedly subjected to transitions from elastic to plastic strain. The specimen stiffness changes significantly and suddenly at the turn-around points. The test frequency, though, is usually less than 1 Hz, which means that there is little dynamic content in the feedback signals. Traditional "black-box" adaptive control methods are not suitable for this problem because they rely on the test signals being "persistently exciting" (dynamically rich). In contrast, the Instron scheme of continuous updated PID control does not impose restrictions on the type of test signal. It has no difficulty compensating for stiffness changes during LCF testing.

Thus, the Instron Adaptive Controller has the following advantages:

- A tuning experiment is not required every time a different type of specimen is loaded into the testing system. The operator simply loads the new specimen and, without applying any special signals, the adaptive algorithm makes the necessary changes to the controller.
- Stiffness changes that occur during a test are compensated for without the use of probing signals. This is possible even when the test signals are not persistently exciting.
- Rapid stiffness changes can be tracked more responsively.

The Instron Adaptive Controller

Figure 6-3 shows how the PID terms are updated in the Instron Adaptive Controller. The lower part of the figure, including the PID controller, servovalve, actuator, test specimen, and the mode selector, is the standard control loop. When Adaptive Control is enabled, PID parameters are continuously updated from stiffness estimates obtained from the Position, Load, and Extension signals by the stiffness estimator shown at the top of the figure. These estimates are used by the controller design algorithm to directly update the PID terms so that the quality of the controlled waveform is maintained as stiffness changes. By the same means, a specimen with a different stiffness can be tested without having to retune the PID controller.

The controller design algorithm has to be initialized with start-up parameters. These are provided automatically by the commissioning parameter estimator when the system is first commissioned, and during Auto-Tuning. The start-up parameters are fixed according to testing system configuration. They do not change with specimen type or stiffness. This is why commissioning or auto-tuning only needs to be repeated if testing system components are changed. This is discussed in the next section.

The PID terms are bounded between maximum and minimum limits to prevent the updating algorithm from setting values that could make the control loop unstable. A status message on the Front Panel indicates when an attempt is made to exceed one of these limits. The limits are set automatically during Auto-Tuning.

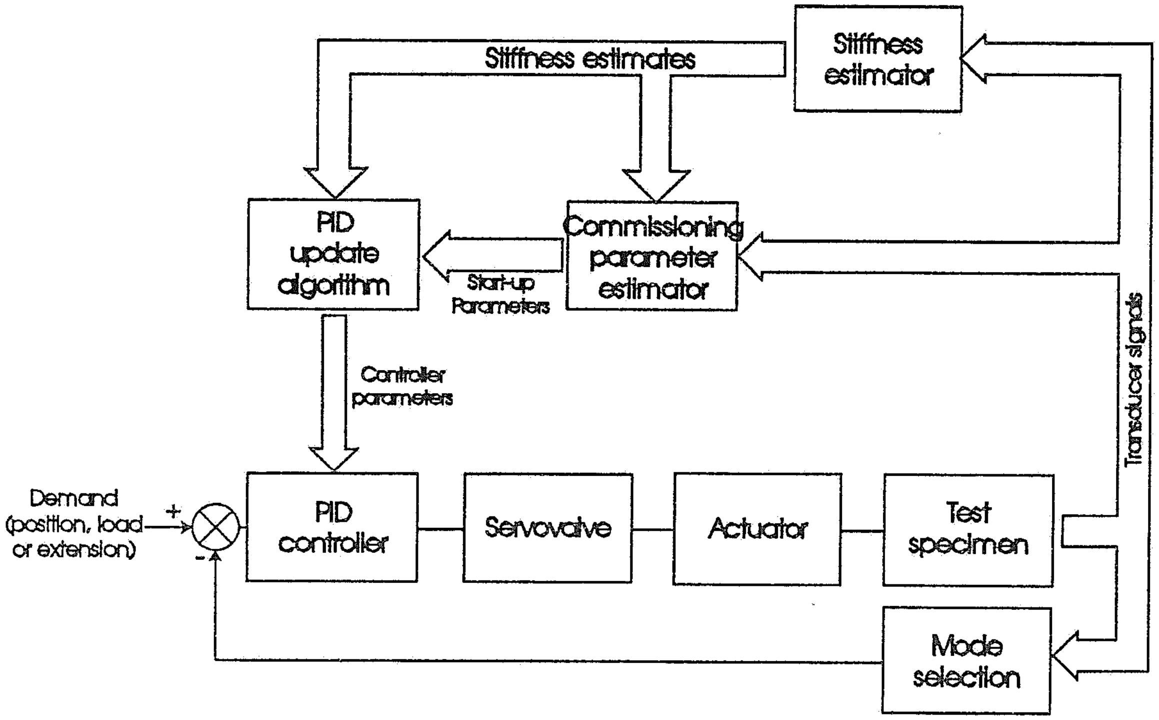


Figure 6-3. Adaptive Control Block Diagram

An important limit is the maximum gain allowed in Load Control. This prevents inertia forces detected by the load cell from making the control loop unstable when the test specimen becomes soft. These forces are the result of mass attached to the load cell, moving in sympathy with the load frame and actuator. The attached mass could be a specimen grip, pull rod, or some custom specimen holding fixture. Mass attached to the moving piston, and mass attached to the load cell both contribute to this effect. Therefore, minimizing these masses is one way of reducing inertia pick-up and of increasing the stiffness range of Adaptive Control. Another solution is to dynamically compensate the load cell to cancel the inertia forces. This is recommended when testing soft specimens.

Obtaining the Start-up Parameters

Before Adaptive Control can be selected, the start-up parameters referred to in the previous section must be derived. To get the parameters, Start-Up Commissioning and Auto-Tuning must be conducted. It is not possible to select Adaptive Control until both of these processes have been completed.

Start-Up Commissioning

The sole purpose of Start-Up Commissioning is to determine the stiffness of the hydraulic actuator. Adaptive Control needs this information because the sensitivity of the testing system response to specimen stiffness depends on how stiff the actuator is. Actuator stiffness is affected by both the stroke and the force rating. Short stroke, large-force actuators are stiffer than long-stroke, low-force actuators.

Start-Up Commissioning only needs to be done once, at the factory when the testing system is first built. After that, commissioning only needs to be repeated if the actuator is changed to one of different stroke or force rating. Re-commissioning is performed using a personal computer and Instron's "Start-Up" software.

The program prompts the user to enter information about the force and stroke of the new actuator. This can be found on the actuator label and is used by the program to calculate actuator stiffness.

Auto-Tuning

Auto-Tuning provides the remaining start-up commissioning parameters. Auto-Tuning must be conducted in each control mode, but cannot be started in any mode until a valid Start-Up Commissioning has been carried out. It is not possible to select Adaptive Control in a mode that has not been previously Auto-Tuned. Also, transferring to an un-tuned mode is prevented while Adaptive Control is active.

Auto-tuning performs three tasks:

1. It sets the optimum PID terms for the current mode. These are stored in the Model 8500 PLUS non-volatile memory as reference values from which Adaptive Control derives working PID terms to suit specimens of different or varying stiffness. Also stored are stiffness estimates recorded while the optimum PID terms were being derived.
2. It measures noise on the transducer signal so that it can automatically set the stiffness estimator pre-filter.
3. It sets minimum and maximum gain values for Load and Strain control and stores these in the Model 8500 PLUS non-volatile memory. These limits protect the system from closed loop instability by placing bounds on the range over which Adaptive Control can update controller terms (see the section that describes how Adaptive Control works for a discussion of the importance of the Load control maximum gain limit).

Auto-Tuning can be started from the Front Panel or by using a GPIB command. The PID terms are automatically adjusted while a stream of small-amplitude square-wave commands is applied. The default amplitudes are ±0.2 mm for Position control, ±2% of the load cell dynamic range for Load control, and ±0.5% of the extensometer range for Strain control. These defaults can be changed, but care should be taken not to choose too small an amplitude. Very small amplitudes give false results.

When Auto-Tuning has obtained optimum PID terms, the function generator is stopped to allow signal noise to be measured. Noise measurement requires zero suppression, and the Front Panel SUPPRESSION LEDs will be seen switching on and off. When Auto-Tuning the Position channel, noise measurement is followed by a small amplitude sinewave burst. This is used to measure the magnitude of acceleration coupling of the actuator motion into the load cell.

In Position control, Auto-Tuning must be conducted without a specimen. In Load control, any stiff, linearly elastic specimen can be used. Conduct Auto-Tuning near zero load with the actuator as near to midstroke as possible. It is essential that the stiffness of the specimen remains constant while Auto-Tuning is underway. Apply a small preload if the test fixture or specimen is such that there is a possibility of through-zero backlash. A preload will also be needed if the specimen cannot withstand tensile and compressive loads. For Strain control, it is important to Auto-Tune with the same extensometer that is to be used in subsequent materials tests. Auto-Tune Strain control using a specimen that is intact.

Note *Auto Tuning cannot be performed on a channel while that channel is Cross-Compensated, or while the Axis is in the Slave mode in a multi-axis system.*

Once Auto-Tuning has been performed, it needs to be repeated only if one of the following is changed:

- The servovalve is changed (retune all modes)
- The grip or specimen attachment fixture is changed (retune all modes)
- The load cell is replaced (retune all modes)
- The extensometer is changed (need to retune only the affected Strain channel)
- The Model 8500 PLUS Tower is connected to a different load frame (retune all modes)

It is not necessary to retune if a different specimen is fitted, or if the position of the crosshead is changed. Adaptive Control automatically compensates for any resulting stiffness change caused by either of these events.

Ensuring Accurate Stiffness Estimates

The accuracy of the Start-Up Commissioning and Auto-Tuning processes, and of Adaptive Control itself, is affected by the quality of stiffness estimates. These are provided by the stiffness estimator from available transducer signals. To ensure good stiffness estimates, it is important that the ranging on all channels is set to AUTO. This assists the estimator by maximizing the resolution of the transducer signals.

Actuator position is used by the estimator in all modes of control, including Load and Strain. It is derived from the actuator LVDT. As the LVDT is a long-travel device, ranging down when the actuator moves away from mid-stroke will reduce the resolution of Position data. This is not a concern during normal testing, but can slow down the responsiveness of the stiffness estimator. To prevent this, the actuator should be operated about mid-stroke. This is particularly important when testing stiff specimens for which actuator movement is very small. Certain test arrangements, though, prevent operation near mid-stroke. In this event, signal resolution can be restored by zero-suppressing the Position channel, and this is strongly recommended.

Enabling/Disabling Adaptive Control

The operation of adaptive control is completely transparent to the operator. When adaptive control is active, real-time stiffness estimates are used to modify the PID terms. Performance is maintained at the commissioned condition as the specimen stiffness changes or if a different specimen is installed.

Disabling adaptive control breaks the connection between the stiffness estimator and PID adjustment. The PID terms will remain fixed at their last set values, but can be manually altered. The stiffness estimator continues to run when adaptive control is turned off so that Model 8500 internal functions and application programs can make use of stiffness information.

Summary

It has been demonstrated, through various studies, that the performance of a servohydraulic materials testing system can benefit from an Adaptive Loop Controller. Specimen stiffness changes, and testing of specimens of differing stiffness, can cause the loop-shaping parameters to be incorrect, even though loop-shaping was initially set up properly.

With the Model 8500 PLUS, Adaptive Control eliminates these problems by continually updating the PID terms according to real-time estimates of the testing system and specimen stiffness. Unlike traditional black-box adaptive control, Instron Adaptive Control can do this even when the test signals are not persistently exciting (dynamically rich).

The updating algorithm is automatically initialized with the fixed parameters of the testing system by commissioning and auto-tuning processes when the system is first built. These need to be repeated only if system components are changed.

Adaptive Control removes the need for a tuning experiment every time a different type of specimen is tested. It also maintains the quality of controlled waveforms in test during which stiffness changes. The real-time nature of the algorithm means that in tests like low-cycle fatigue, it corrects for the significant stiffness changes that occur during each strain cycle.

Chapter 7
Limits and Event Detectors

Outline

- Use of Limits and Event Detectors ...... Page 7-2
- Limits .... Page 7-4
- Event Detectors .... Page 7-12

Limits and Event Detectors are basically similar functions. The differences between Limits and Event Detectors are discussed in this chapter, as well as how to use each of these functions.

Use Of Limits And Event Detectors

Limits and Event Detectors are used to mark specific points during a test, and to take actions when those points are reached. You have full control over where these points are set and which actions take place. Thus, Limits and Event Detectors have basically similar functions and can have the same actions when they are triggered. However, Limits and Event Detectors have very different and distinct objectives.

Limits set bounds within which a test must be performed. They prevent system operation in regions that may constitute a hazard to personnel or could result in equipment damage. Limits are used purely as a safety device and have no other purpose.

Limits perform their safety function by establishing windows of safe operation beyond which operation of the system could result in unsafe conditions. You are able to choose and set the maximum and the minimum values for these limits, and the action to be taken by the system should any limit be exceeded.

Event Detectors, on the other hand, are used to mark the progress of the test and the attainment of specific test objectives, *e.g.* the occurrence of maximum and minimum peaks. Event Detectors can initiate a wide variety of actions when triggered, they can be used as an aid in defining different sections of a test, or to set up block programming of the test.

Event Detectors respond to actual, live events as they happen in real time, and thus they relieve the operator of monitoring the test and performing these tasks manually.

This can speed up the pace of the test significantly. They also relieve an attached computer of the task of continuously polling the Model 8500 Testing System to see if a specified condition has been reached.

To summarize, Limits are used as safety devices to mark the bounds within which a test must be performed, and to take specified actions should the test parameters exceed these bounds. Event Detectors monitor a test for the attainment of specific test objectives, and take specified actions once those objectives are attained.

You should ensure that you are fully aware of the differences between Limits and Event Detectors. Limits should always be set before a test is performed to ensure the safe operation of the system.

Limits

The Model 8500 Testing System provides for a maximum and a minimum Limit on each transducer channel. Together, these Limits define a window of operation which is considered safe and within which the transducer signal must remain for continued test operation.

If the transducer signal exceeds the boundaries of the window, the Limit trips to indicate an unsafe situation. The test can be shut down according to a pre-selected action, and many normal operations are locked out until you clear the Limit, indicating to the system that the problem has been corrected.

The transducer data is monitored at a rate of 1 kHz; that is, every 1 millisecond. A Limit is tripped whenever the feedback waveform crosses the set limit, and sensing of that point will occur within 1 millisecond. The Limits can thus be regarded as being level triggered.

Defining a Limit

To fully define a Limit, you must select a Limit level, a Limit action, and activate the Limit by setting the state to ON. Optionally, you can choose to drive any or all of the digital output lines to a preset state upon a Limit trip for the purpose of controlling ancillary equipment.

From the GPIB, you can optionally specify an arbitrary buffer of commands to be executed when a Limit trips. Refer to the Sections "Command Execution on Limit Trip" on page 7-9, and "Limits and the Computer" on page 7-10.

Limit Level

The Limit level is entered in engineering units on the Front Panel, or in fractional format from the GPIB. It is vitally important to note that, regardless of the Zero Suppression state for a given channel, Limit settings for that channel are relative to the physical units for that transducer, not the suppressed units. For example, a Limit set to 10.0 mm will trip when the actual actuator displacement from its center point reaches 10.0 mm, even though the Position signal might be Zero Suppressed by 20.0 mm, meaning the live data display for the Position channel would be reading -10.0 Δmm.

Limit Actions

There are six Limit actions. These actions are defined as follows:

- **NONE** - No action is taken. Used to test the Limit trip level. The Front Panel will indicate the tripped condition.
- **RESET** - The Waveform Generator and Ramp Generator both perform their normal reset action.
- **TRANSFER AND HOLD**- Transfers the control mode to the limiting channel and sets the Set Point to the limit setting.
- **UNLOAD** - Transfers control mode to Position and activates Load Protect at 0.2% of full scale load. You must manually reset Load Protect and the tripped Limit to restore normal functioning.
- **STOP** - This causes a transfer to Position control, holds at the current position with the Waveform and

Ramp Generators off, and locks out actuator control command functions such as mode change waveform/ramp state.

- **ACT OFF** - Turns off the actuator hydraulic power. This can be optionally wired at the Tower Rear Panel to turn off the hydraulic pump. You must manually reset all tripped Limits to re-enable the actuator power.

In a structures or multi-axial system, the following system actions are available:

- **SY.STOP** - The system transfers to position control and holds at the current position, and can be set to shut off hydraulic power.
- **SY.RESET** - In a multi-axial system, all axes return to the Set Point level in the envelope control time.
- **SY.UNLOAD** - In a multi-axial system, all axes transfer to position control simultaneously and turn Load Protect ON with a small load value.

In addition to the actions above, the following global actions and lockouts occur when any active Limit trips:

- For all actions except NONE, the Waveform and Ramp Generators go to the OFF state. For the RESET action, they get to off by first performing their normal reset action. For all other actions, the occurrence of a mode transfer puts them in the OFF state directly. For the NONE action, the generator states are not effected.
- Further commands to the Waveform and Ramp Generator states are locked out until the Limit is

cleared. However, if the action was NONE, a RESET or FINISH command to the Ramp Generator is accepted, and a RESET command to the Waveform Generator is accepted.

- Any pending next mode and next Waveform and Ramp Generator information is overwritten and the next mode command is locked out.
- When controlling on a channel with a tripped Limit, the Set Point is bounded by the tripped limit level(s). In the case of the Position channel and Position limit(s) with an action of TRANSFER AND HOLD, the jog function is also bounded by the tripped Limit level(s).
- Commands to activate new Limits are locked out, although Limits that are already active remain so.
- Any active Event Detectors go to the OFF state, except those designed for event driven data logging. Further state change commands to Event Detectors are locked out.

Limit Action Priorities

- In the event of multiple Limit trips, the second and succeeding limit actions are taken only if allowed by the system state at the time the Limit trips. The Limit actions are prioritized, from highest to lowest, as ACTUATOR OFF, STOP, UNLOAD, TRANSFER AND HOLD, and RESET. A Limit action is taken only if it does not conflict with a pending higher priority action.

- For example, if a Limit trips and performs the RESET action, and subsequently another Limit with action TRANSFER AND HOLD trips, the action of the second Limit will be taken normally. Similarly, if the first Limit action were also TRANSFER AND HOLD, then the second Limit action would be handled normally. In contrast, if the first Limit action had been UNLOAD or STOP, then the action of the second Limit would be locked out.
- These priority rules apply equally well in the case where either the STOP state or Load Protect state were activated manually. Also, in some cases, a higher priority state does not conflict with a lower priority state. For example, if one Limit with action ACTUATOR OFF trips, and then a second Limit with action TRANSFER AND HOLD trips, the TRANSFER AND HOLD action would be taken even though the actuator is in the off state. All the Limits must be cleared before the actuator can be turned on again, but the system will be in the mode of control of the second Limit.

Limit Monitoring

By setting and activating a Limit on a transducer, you request the system to protect itself by monitoring that transducer data. The system performs this activity at the 1 kHz sampling rate. There are two important implications of this monitoring. First, any realtime event which causes the data to be invalid on this channel, such as saturating a manual range or unplugging a transducer, means the system can no longer protect itself, and hence, the Limit will trip in the normal manner (in the case of saturation, the Limit trips if the direction of saturation equals the sign of the Limit.) Second, any command action that would invalidate the data for that channel is locked out. Thus, Calibration, Balance, Zero Suppression, and Acceleration Compensation state change commands are all locked out.

Furthermore, when a Limit is active, the action requested is preprogrammed to be taken in realtime when the Limit trips, i.e. within 1 millisecond. Changes in the Limit action are locked out for active Limits to avoid the possible confusion between the old action and the new action if the Limit were to trip during the change of the action parameter.

Command Execution on Limit Trip

Each Limit in the system also has a preprogrammable command buffer. Each buffer can hold up to nine Model 8500 System commands. When a Limit trips, the commands in the associated buffer are executed after the selected Limit action is completed, but before any new externally generated commands are. You are free to use any commands in the buffer, but each command is checked for validity just before execution according to normal rules. Thus, if the program buffer for a given Limit contained a command to balance that channel, the command would be rejected. The Front Panel uses these buffers to provide the Digital Output Line control feature. When a Limit is activated from the Front Panel, any command buffer information for that Limit stored via the GPIB is overwritten by the program sent from the Front Panel. Refer to the Section “Limits and the Computer" on Page 7-10.

Limits and Zero Suppression

When Zero Suppression is active, you can turn a Limit on and off. However, if you already have a Limit on, you cannot turn on Zero Suppression because that action might cause the Limit to trip during the suppression process, with unexpected results due to the requested Limit action.

Limit Lock

A Limit Lock feature is available at both the Front Panel and the GPIB. The purpose of the lock is to prevent accidental changing of the Limits once they have been set. For example, you might set a Load Limit and then lock the Limits before entering computer control to debug an application program. If the program contained an error which accidentally sent any Limit-related command, the command would be rejected. In order to change a Limit parameter, the computer would first have to unlock the Limits. Then all Limit related commands would function normally. Similarly, locking the Limits prevents a new operator from inadvertently changing Limits that have been set previously.

Limits and the Computer

All Limit values, actions and operational states can be addressed from an external computer via the IEEE-488 Interface and the appropriate commands.

For more information on Limits and the Computer, see the Model 8500 GPIB Interface manual for the following:

Refer to GPIB Message Header number 121 for controlling Limit state.

Refer to GPIB Message Header number 122 for setting Limit value.

Refer to GPIB Message Header number 123 for setting Limit action.

Refer to GPIB Message Header number 138 for preprogrammed command buffer control.

Refer to GPIB Message Header number 326 for limit locking control.

Event Detectors

Event Detector Types

The ten different event types which an Event Detector can be programmed to detect are:

- THRESHOLD Occurs when the selected input signal passes through the programmed threshold in the selected direction.
- PEAK Occurs when a local peak in the feedback signal has been found by the peak monitor module.
- INCREMENT Occurs when the feedback signal changes by more than a programmable increment in either the positive or negative direction.
- BREAK Occurs when the feedback signal drops in absolute value by a selectable percentage within a selectable time increment.
- COUNT The event occurs when a pre-selected number of waveform cycles or segments have taken place.
- ENHANCED COUNT Occurs when a pre-selected number of waveform cycles, segments, or time have taken place.
- DIGITAL The event occurs when the digital line being monitored changes to, or is already at, a selected logic state.
- ERROR The event occurs when the error signal to the servovalve goes outside of a pre-selected window of operation.

- GPIB TRIGGER The event occurs upon receipt of a Group Execute Trigger command from the host computer via the GPIB bus.
- SYSTEM BUS The event occurs when the sync-link system bus line being monitored changes logic state.

Threshold

There are four separate events which may be detected using threshold event detectors. These are maximum and minimum level, and maximum and minimum underpeak.

These events are all defined as a simple signed comparison between an input signal and a preselected threshold value. You select the threshold value and the sign required for comparison.

For a positive sign, the event is defined as a transition of the input signal through the threshold value with a positive slope. For a negative sign, the event is defined as a transition through the threshold value with a negative slope.

Remember that a transition through the threshold must be made. Figure 7–1 illustrates how an Event Detector with a negative sign (Minimum Level) can be armed when the input signal is already less than the threshold value.

For the Event Detector to trip, the input signal must increase to greater than the threshold value and then decrease to cross the threshold value in the required direction.

You can also choose the source of the input signal required for the threshold detector from Feedback, Mean, Amplitude or Peak.

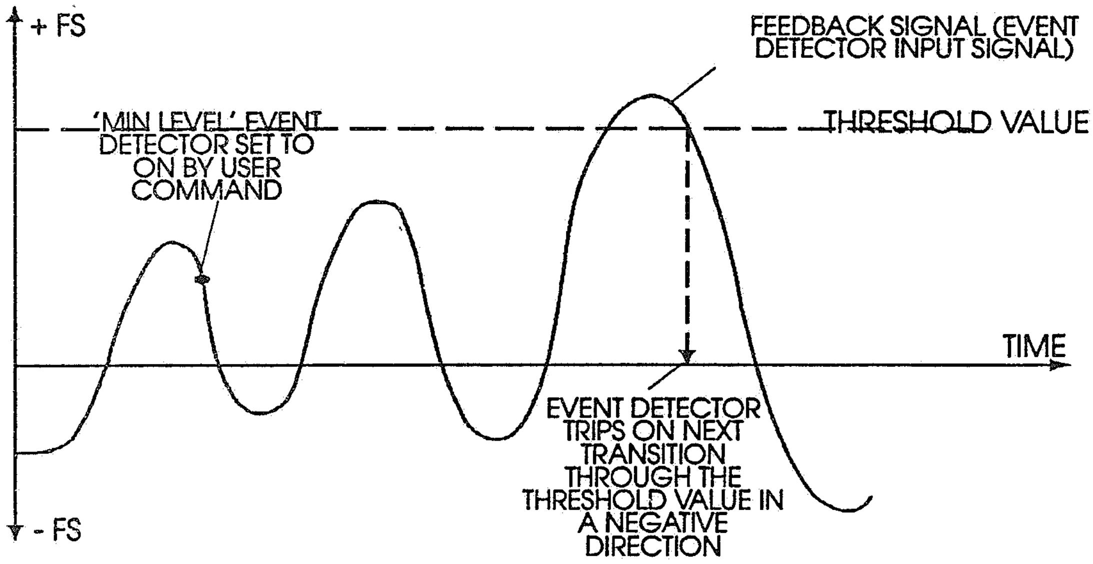


Figure 7–1. Event Detector Transition

Selection of Feedback means that the current feedback signal is compared directly to the threshold value. If the signal crosses the threshold value in the direction selected by the sign, the event detector trips.

Selection of Mean compares the mean value of the waveform to the threshold value. The mean value is calculated using the following equation:

$$Mean = \frac{(local\_max + local\_min)}{2}$$

The mean value is recalculated every time that a new local maximum or minimum is found in the feedback signal.

Figure 7–2 shows how the mean value is updated each time a new peak is encountered, and how the Event Detector trips when the mean value crosses the threshold value.

Selection of Amplitude compares the value of the waveform amplitude to the threshold value. The amplitude value is calculated using the following equation:

$$Amplitude = \frac{(local\_max - local\_min)}{2}$$

The amplitude value is recalculated every time that a new local maximum or minimum is found in the feedback signal.

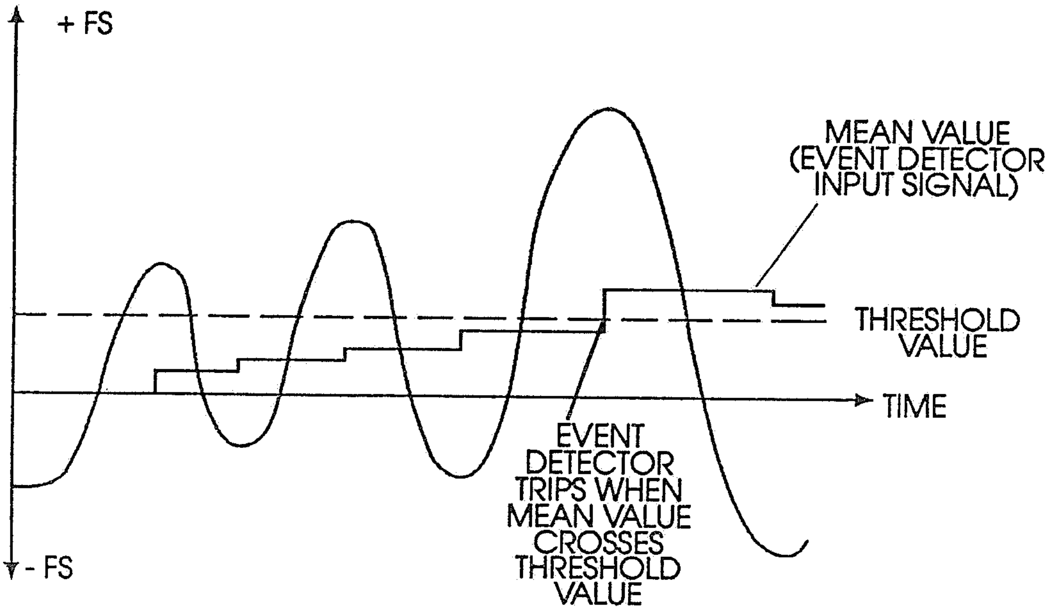


Figure 7–2. Mean Signal Input Update

Figure 7–3 shows how the amplitude value is updated each time a new peak is encountered, and how the Event Detector trips when the amplitude value crosses the threshold value. The foregoing input signal sources are all used for maximum and minimum level Event Detectors.

Remember that amplitude is always a positive number. This means that the threshold setting, when using this input signal, must also be positive. When the Peak input signal is selected, either the minimum or the maximum peaks are chosen automatically, dependent upon the sign chosen for the comparison, as shown in Figure 7-4.

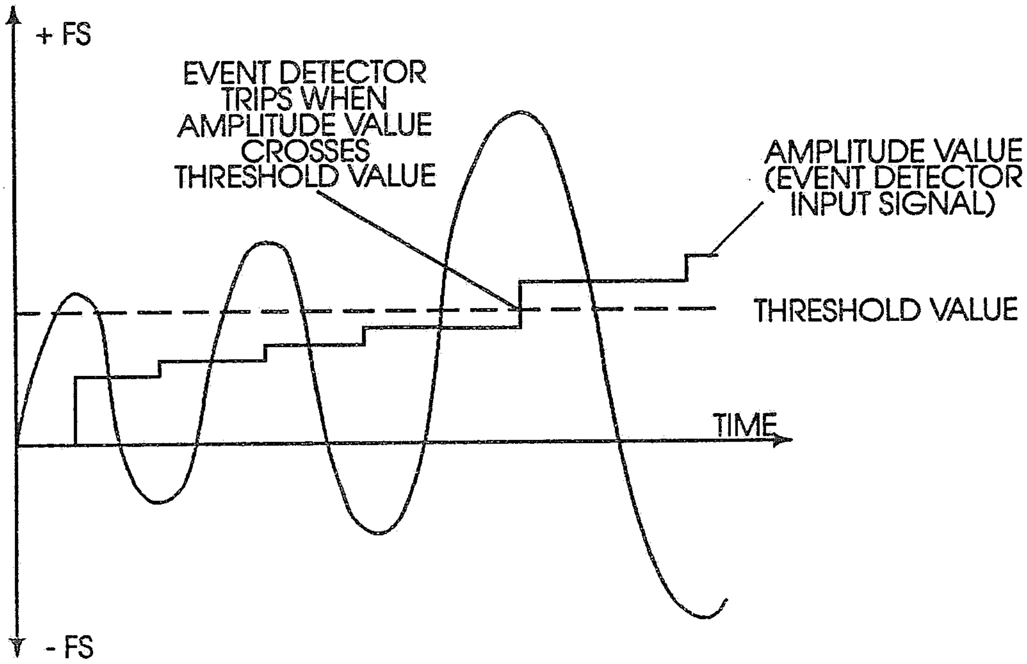


Figure 7–3. Amplitude Signal Update

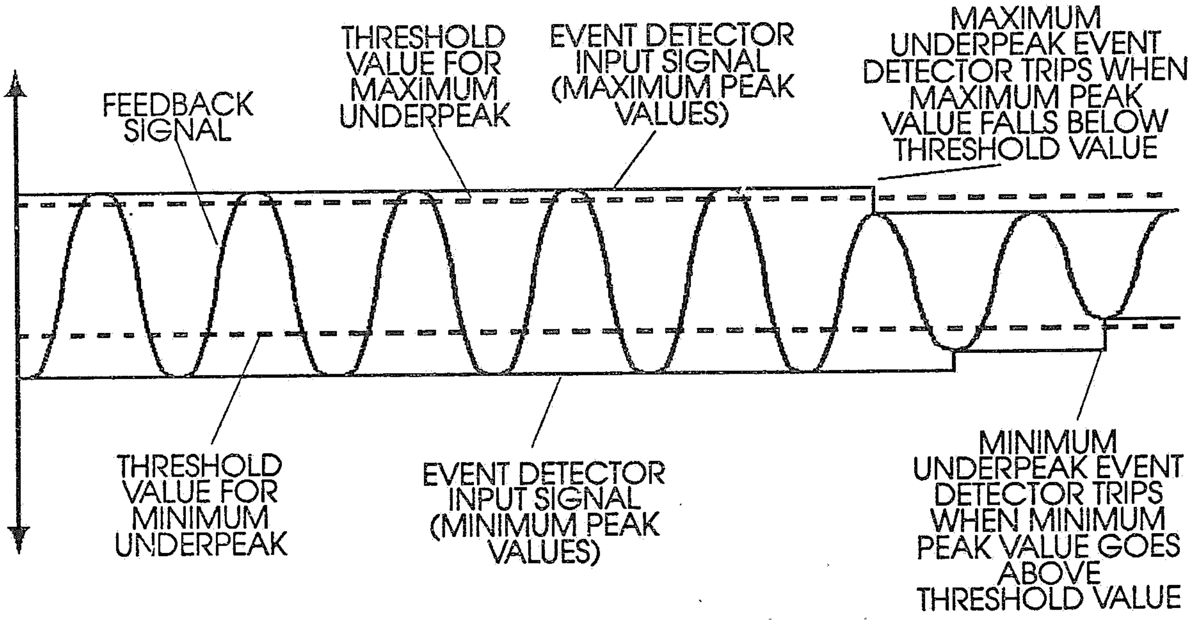


Figure 7–4. Maximum and Minimum Underpeaks

Peak

The Model 8500 Firmware contains a standard peak detection algorithm which detects each maximum and minimum peak occurring on a waveform. The Peak type of Event Detector defines each of these peaks as a possible event, dependent upon the sign chosen.

You can choose from Positive, Negative and Both. Positive considers peaks with a positive pre-peak slope, i.e. maximum peaks, to be events. Negative considers peaks with a negative pre-peak slope, *i.e.* minimum peaks, to be events. A selection of Both results in all peaks being considered events.

This Event Detector does not use the value of the peak in any way, just the true or false condition of whether the peak detection algorithm detects a peak on the waveform.

The Peak Event Detector automatically resets after event detection, and is typically used in conjunction with data logging as a data capture marker.

Increment

The Increment detector declares an event whenever the feedback signal changes in absolute value by an amount equal to or larger than a preselected value from its value at arming or at the last increment event. Unlike threshold detection, the specified operating value for this Event Detector is an increment in signal, not an actual level. Also, this event is unsigned, so either a positive or negative increment causes event detection.

Internally, the event detector remembers the value of the signal at the last event for use in calculating the increment.

When a new event is detected, this value is updated by adding or subtracting (as appropriate to the increment sign) the specified operating value to the stored last value.

The Increment Event Detector automatically resets after event detection, and is typically used in conjunction with data logging as a marker for data capture.

For a very fast moving signal, the difference between the signal and the stored last value can build up to many times the specified operating value. This can result in event detection occurring after the signal has stopped changing and can be considered normal operation.

Figure 7–5 shows a section of a waveform with arbitrary incremental values superimposed. Note that an event is defined only where there is an absolute change in value from the last recorded value. Hence Event 4 does not take place until the value of the waveform has changed by the required absolute amount from the value recorded at Event 3.

Break

The Break detector defines an event as the drop in absolute value of the feedback signal by a preselected percentage within a preselected time interval. You can select the percentage drop as 50%, 25%, 12.5%, 6.25%, or 3.125%, and you can set the time interval in milliseconds.

In this mode, the Event Detector maintains a copy of the value of the signal at the last check-for-break or at arming. Every specified time interval, the signal is sampled and compared to the last value. If the comparison indi-

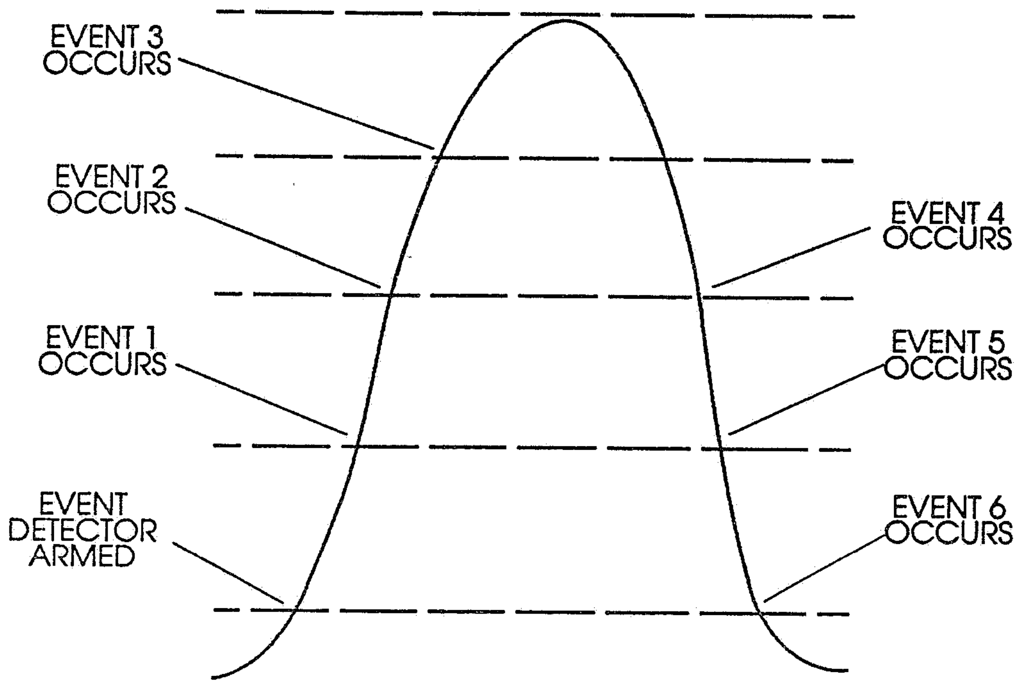


Figure 7–5. Incremental Event Detector

cates a drop in value greater than the specified percentage, break is declared. If not, the current value becomes the last value and the time interval resumes.

Figure 7–6 shows break detection in simplified form. The percentage drop in signal value during the first time interval is slight. Break occurs during the second time interval, leading to a larger percentage drop. If the percentage drop is greater than the preselected percentage, the Event Detector will trip.

As a protection against false breaks being detected due to noise when the signal is very small, the break detection algorithm only runs when the absolute value of the signal is larger than 0.5% of full-scale.

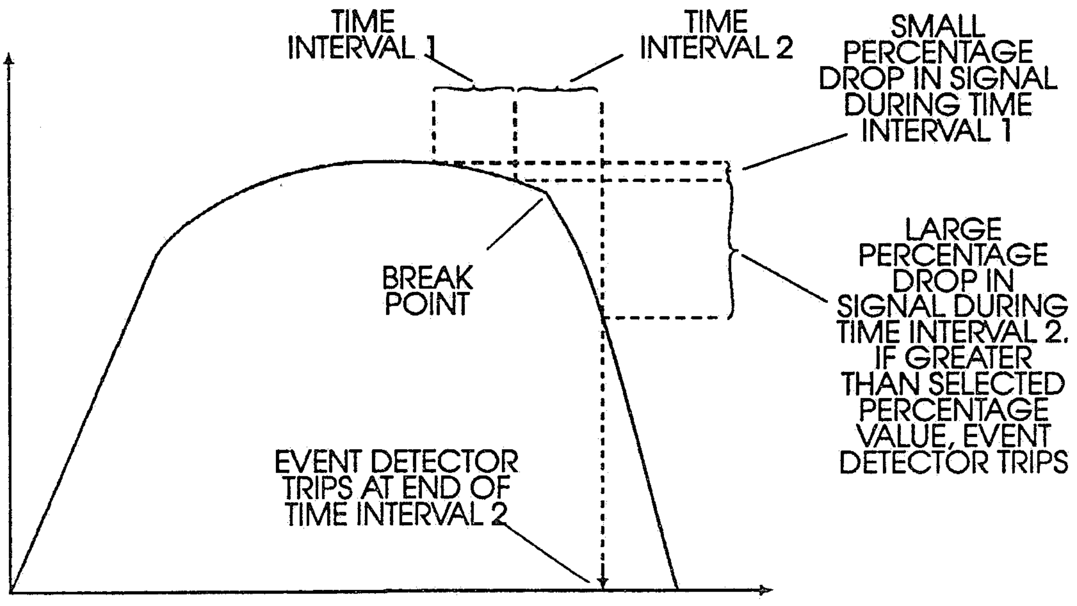


Figure 7–6. Break Event Detector Operation

Count

There are two types of Event Detectors that operate on a count basis. These are Cycle Count and Segment Count.

The Cycle Count type operates with sine, square and triangle waveforms and their haver forms and can be set to detect an event after a preselected number of cycles. The resolution for the count is in whole cycles when operating from the Front Panel and in quarter cycles when operating from the GPIB.

The Segment Count type operates with single-ramp, dual-ramp and trapezoidal waveforms and with random or sample-based waveforms generated using havers to link the points. This can be set to detect an event after a preselected number of segments. A segment can be a single ramp or dwell, or a single haver cycle linking two sample data points.

Enhanced Count

Each Sensor Conditioner card can turn one or more of its Event Detectors into a count type detector. In addition to monitoring quarter-cycles and segments, this type allows detection on total cycles or segments, as well as cycle or segment time. As with the count type detector, all types of cyclic waveforms and ramps are supported. These types of event detectors are only available when operating from the GPIB Computer Interface.

Digital

An Event Detector can be set to monitor a digital input line for an event. There are four types of digital event; Low, High, Low-High and High-Low. These correspond to the logic state of the digital line; i.e. Low corresponds to Logical-Zero and High corresponds to Logical-One.

An Event Detector set to Low will trip immediately upon receiving a Logical-Zero. If the detector is armed when the signal is already at Logical-Zero, then the detector will trip.

An Event Detector set to Low-High will trip only upon a transition from Logical-Zero to Logical-One. If the detector is armed when the signal is already at Logical-One, then the detector will not trip until the next low-to-high transition.

The same rules apply for the High and the High-Low settings, but with the relevant logic states reversed in each case.

Figure 7–7 shows a varying logic state signal, and the positions in which the various settings will trigger.

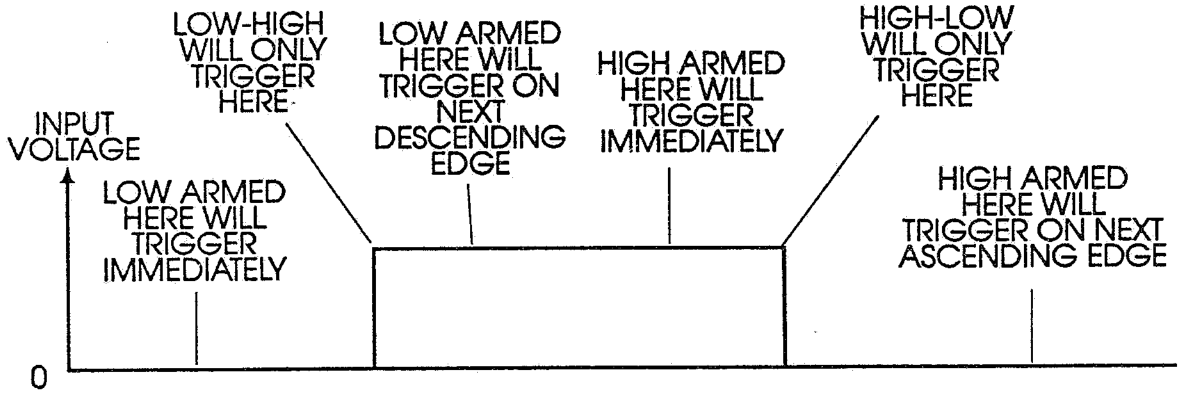


Figure 7–7. Digital Line Event Detector Action

Error

The Master Controller compares the demand signal from the Waveform Generator with the feedback signal from the controlling transducer. Any discrepancy between them is output as an error signal which is used to drive the actuator to reduce the error to zero.

An Event Detector can be set up to monitor the amplitude of the error signal. You can preselect an absolute value such that an event is detected if the error signal reaches or exceeds that value in either a positive or negative direction.

GPIB Trigger

An Event Detector can be set to trip upon the receipt of a Group Execute Trigger (GET) signal from an external computer.

An example of the use of this Event Detector is to synchronize the operation of several devices upon receipt of the GET signal.

This Event Detector can only be set using the external computer.

System Bus

An event detector can be set to monitor one of the sync-link system bus lines for a logic state transition. This event detector behaves in exactly the same way as for the digital events. Refer to that section for details.

Event Detector Access

Event Detectors are programmed using either the Model 8500 Front Panel or the external computer. The computer can program any number and all types of Event Detectors. However, the Front Panel can program a maximum of five Event Detectors, of all types except Group Execute Trigger and the enhanced count detectors.

Each Sensor Conditioner card has four independently programmable Event Detectors, designated 1 through 4. Each of these can be programmed to detect a threshold, peak, increment, break or enhanced count event.

Event Detectors 1 through 4 at the Front Panel can be set to program their corresponding area in any one Sensor Conditioner card. Hence, Event Detector 1 can be set to program either Position Event Detector 1, Load Event Detector 1, Strain 1 Event Detector 1 or Strain 2 Event Detector 1, and so on. Any of Event Detectors 1 through 4 at the Front Panel can also be programmed to monitor its respective digital input line instead of a Sensor Conditioner card area.

Event Detector 1 at the Front Panel can be set to monitor an error signal event instead of a Sensor Conditioner card area or its digital line.

Event Detector 5 at the Front Panel can be set to monitor a count type event, either a cycle count or a segment count. The only Event Detector type which is not accessible by the Front Panel is the Group Execute Trigger.

Figure 7–8 shows how the Front Panel and the external computer access the various Event Detectors. The Front Panel is shown divided into the five Event Detector setup areas.

Event Detector 1 is shown set up on the Position Sensor Conditioner card Area 1.

Event Detector 2 is shown set up on the Load Sensor Conditioner card Area 2.

Event Detector 3 is shown set up to monitor Digital Input Line 3.

Event Detector 4 is shown set up on the Strain 2 Sensor Conditioner card Area 4.

Event Detector 5 is shown set up on the Cycle Counter.

The external computer can handle all possible Event Detectors, including the Group Execute Trigger, which is not available from the Front Panel.

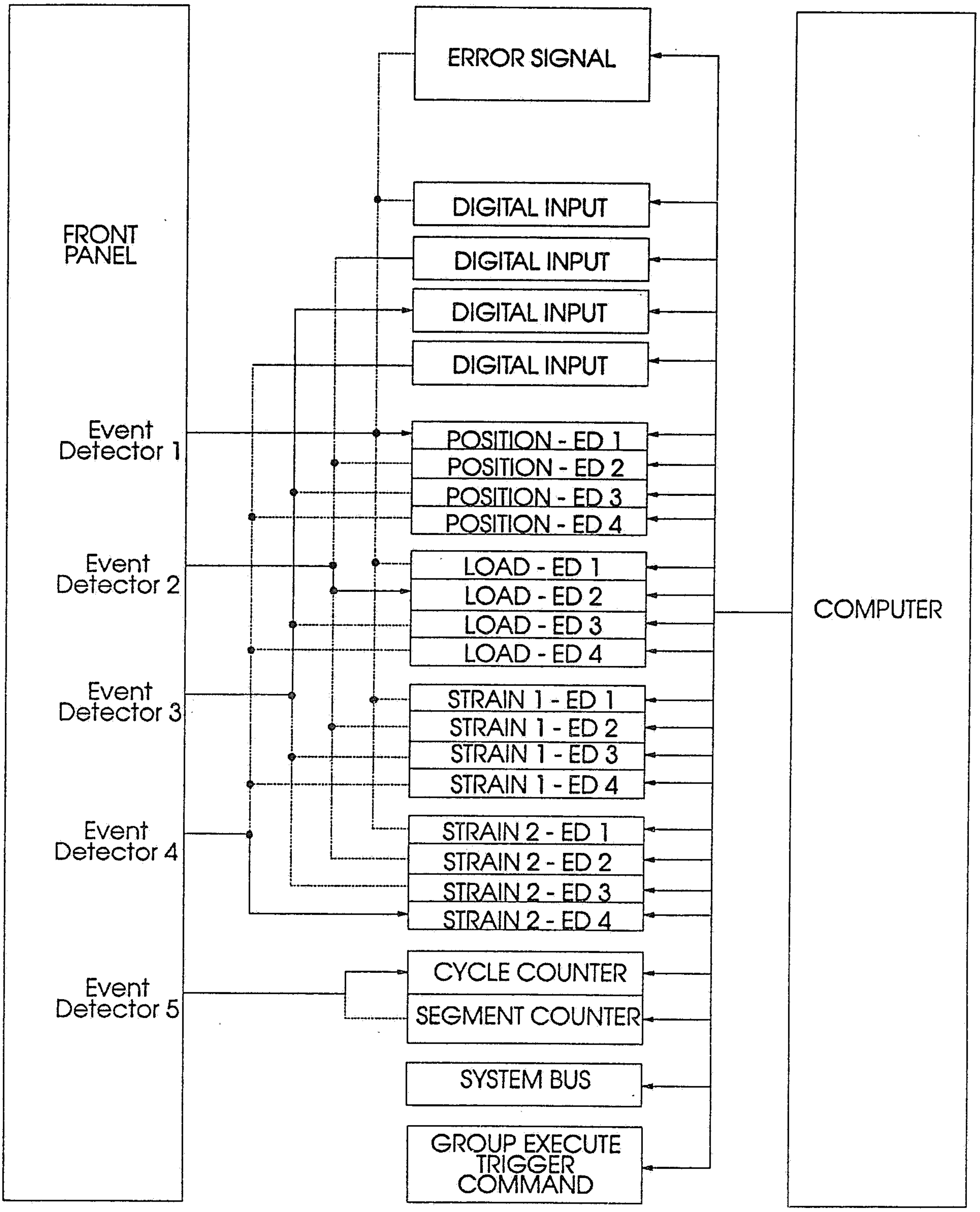


Figure 7–8. Event Detector Access

Event Detector Actions

Realtime Actions

The realtime actions which an Event Detector can be programmed to take (only one at a time) when the programmed event occurs, are:

- HOLD Waveform and ramp generation go to the HOLD state, if running.
- STOP Waveform and ramp generation go to the OFF state and the controller transfers to Position control with the set level set to the current position.
- MODE TRANSFER Causes a mode transfer to the pending next mode.
- ACTUATOR OFF Causes the actuator enable line to the Tower Rear Door to be disabled. This will turn off either the manifold pressure or the pump, depending on how this function is wired.
- DATA LOG STROBE Causes a vector of data to be logged on the next sampling period if the data logger is in the STARTED state.
- NO ACTION No real time action is taken. Can be used for debugging Event Detector setup.
- FINISH Causes a cyclic waveform to stop at the end of the current cycle, or a ramp waveform to stop at the current level and to reset the set-point to that level.

- RESET Causes a cyclic waveform reset envelope to ramp down in amplitude, or a ramp waveform to return to the start point at a fixed rate.
- UNLOAD Causes a transfer to load control with the set-point set to 0. The waveform and ramp generators go to the OFF state.
- CYCLE Causes a change of direction of a ramp waveform.
- SYSTEM STOP Causes the same action as for a single-axis system, but action occurs on *all* axes of a multi-axial system.
- SYSTEM HOLD Causes the same action as for a single-axis system, but action occurs on *all* axes of a multi-axial system.
- SYSTEM TRANSFER Causes the same action as for a single-axis system, but action occurs on *all* axes of a multi-axial system.
- SYSTEM RESET Causes the same action as for a single-axis system, but action occurs on *all* axes of a multi-axial system.
- SYSTEM CYCLE Causes the same action as for a single-axis system, but action occurs on *all* axes of a multi-axial system.
- SYSTEM DATA STROBE Causes the same action as for a single-axis system, but action occurs on all axes in a multi-axial system.

Data Logging Actions

In addition to whichever realtime action is selected, an Event Detector can be programmed to also take one of the following three actions regarding data logging control:

- **START** Causes all data logging modules in the STOPPED state to change to the STARTED state.
- **STOP** Causes all data logging modules in the STARTED state to change to the STOPPED state.
- **NO EFFECT** Has no effect on data logging.
- **SYSTEM** Event Detector action causes a system-wide (all axes of a multi-axial system) data logging action.

Event Detector States

The default state for all Event Detectors is OFF. This means the Event Detector is not performing the required actions to detect the programmed event. In this state, any of the parameters can be set at will. To activate the Event Detector, once it has been programmed as desired, you command it to the ON state. The Event Detector then begins the necessary processing to detect the event. When the event is detected, the Event Detector goes to the TRIPPED state and performs the realtime and data logging control actions as required.

At this point, different types of Event Detector take different subsequent steps. The types can be categorized into two categories: the single shot Event Detector which stays in the TRIPPED state and must be turned OFF by the user, and the repeating Event Detector which automatically resets and returns to the ON state upon ately after performing the normal actions. Hence, the TRIPPED state for a repeating Event Detector is really an internal detail and is never seen by the user.

Single shot event types denote major events which would normally indicate a transition point between distinct regions of a materials test. The Threshold, Break, Count, Digital, Error, System Bus, and GPIB Trigger types fall in this category. Realtime actions HOLD through ACTUATOR OFF would most commonly be used with this type.

Repeating event types are meant to provide even sampling during a particular section of a materials test and would most commonly be used with the DATA LOG STROBE action. Increment and Peak event types make up this category. In addition, the Threshold type, used in conjunction with the Cycle action, also provides a repeating type.

All Event Detectors have a PREPARED state, in which the Event Detector is inactive, as in the OFF state, but is monitoring the universal Arm Command bit. When this bit is set, it allows for a realtime transition from the prepared to the ARMED state without using the slower background command.

When in the ARMED state, single shot Event Detectors respond to the universal Disarm command. They also generate a universal Disarm command when they trip. Thus, if more than one single shot detector are armed simultaneously, the first one to trip will generate the Disarm command (after taking realtime and data logging action as described previously) and cause all other single shot detectors to go to the OFF state. If the real time action is a "system" action, then all axes of a multi-axial system will respond to the disarm command.

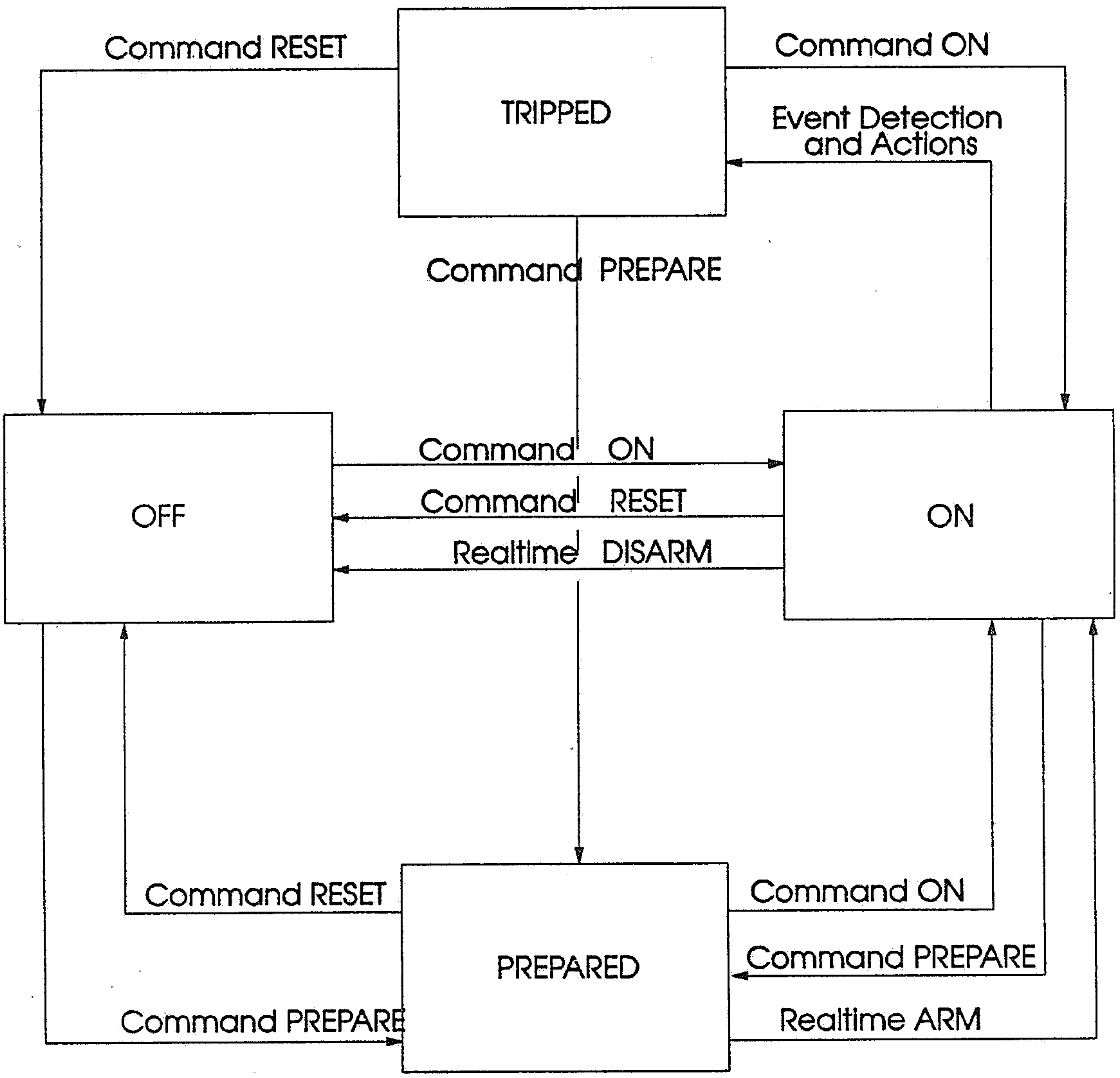


Figure 7-9. Complete Event Detector State Diagram

A full state diagram for single shot detectors is shown in Figure 7–9.

Repeat Event Detectors also have the PREPARED state, however they do not respond to the universal disarm command, nor do they generate this command upon event detection.

Status Change Messages

All the above state changes result in a status change message being generated to both the Front Panel and the GPIB. When performing complex sequencing of arming, preparing, and disarming Event Detectors, these messages are the signals to the host computer that inform it when a new test region has been entered. When the host receives a TRIPPED message, for example, it knows the appropriate realtime action for that Event Detector has already taken place. This realtime action may have started a new region of the test, including a new waveform or ramp, or both, if the transfer action was used in conjunction with the block programming feature. The host computer would then need to set up the event detection needed to capture important information in the current region as well as set up information about the next region and what event or action is needed to get to the next region.

The PREPARED state can be used to aid in this process by allowing much information to be preloaded. A single ARM command then might arm both a repeat Event Detector to take data during a region and a single shot Event Detector to trip to the next region.

Programmable Event Detector Command Buffers

Another tool which can be used to speed up the realtime response of the system to complicated setup sequences is the programmable Event Detector buffer.

A series of normal Model 8500 commands can be stored into a buffer internally and specified to run when a particular Event Detector trips. When this is done, the overhead of communicating the messages over the GPIB and parsing them for errors is done before the critical section and much time is saved when the event actually occurs and the commands are executed.

The Model 8500 can hold up to five of these program buffers simultaneously. A program buffer is both defined and mapped to a specific Event Detector using Command 322.

A buffer can hold up to nine Model 8500 message units, but this can be extended using Command 336. A single command requires one message unit, with the exception of some of the data logging format and control commands, which require two message units.

Programming Event Detectors with the Model 8500 Command Set

As there are a large number of commands relating to the setup of an Event Detector, it is helpful to establish a logical order to issue the commands.

The first and last commands sent should always be the State command since all the other commands are only allowed when the Event Detector state is OFF. The other commands are all independent in the sense that they can be sent in any order and the end result will be the same. Nonetheless, a mnemonic order is useful to avoid confusion. The following suggestions regarding the programming of Event Detectors is specific to an Event Detector within a Sensor Conditioner Card. For full details of the programming of all Event Detectors, refer to the Model 8500 GPIB Manual.

Command Format

All commands which are related to an Event Detector within a Sensor Conditioner Card have the format "Ch, n, s, p".

The "h" value specifies the particular header for the desired command action. The "n" value specifies the number of the desired channel, 1 for position, 2 for load, and so forth. The "s" value specifies the selector of the particular Event Detector desired, having values 1 through 4. The "p" value specifies the parameter value desired.

Different headers require different parameters. In general, the parameter is either an integer which selects from a list or a floating point number expressed as fractional full scale.

Resetting the ED State

The first command that should be sent is the State Command 125, with the parameter set to RESET.

Setting the Event Detector Type

The second command that should be issued is the Type Select since this parameter has implications on what other parameters are necessary and how they are interpreted.

The type is selected with Command 127, which selects both the type of the Event Detector and, in the case of THRESHOLD type, the desired input signal. The first four parameters for this command all select a THRESHOLD type Event Detector with differing inputs, which are feedback, mean, amplitude, and peak value. The last three parameter selections map directly to the other types.

Table 7–1 details the parameter values, the Event Detector type and input.

Table 7–1. Setting the Event Detector Type

COMMAND 127 PARAMETER VALUE	EVENT DETECTOR TYPE	INPUT SIGNAL
FEEDBACK	Threshold	Feedback
MEAN	Threshold	Mean of feedback
AMPLITUDE	Threshold	Amplitude of feedback
PEAK VALUE	Threshold	Peak of feedback
INCREMENT	Increment	Feedback
BREAK	Break	Feedback
PEAK EVENT	Peak	Boolean output from peak detector module

Setting the Event Detector Sign

The next sensible parameter to set is the sign or sense of the Event Detector. Note this is only meaningful if the type selected is THRESHOLD or PEAK. The other types use absolute values for comparisons. The sign is set with the Slope Command 128. For a THRESHOLD Event Detector, this parameter can be set to NEGATIVE or POSITIVE which defines the slope the input signal must have when crossing the threshold. For a PEAK EVENT Event Detector, the parameter can be set to NEGATIVE for minimum peak only, POSITIVE for maximum peak only or BOTH for both minimum and maximum peaks.

Setting the Event Detector Threshold

If the Event Detector type is THRESHOLD or INCREMENT, then the threshold/increment value should be set next. This is done with the Level Command 126. If the type is BREAK, then the time interval should be set using the Break Detect Time Scale Command 135, and the percentage drop should be set using the Break Detect Divisor Command 136.

Setting the Event Detector Action

Next, a realtime action should be selected using the Action Command 129. Any action may be selected, regardless of the Event Detector type. It should be noted, however, that some combinations are usually invalid. For example, selecting the ACTUATOR OFF action with a PEAK Event Detector type would mean the actuator would dump every time a peak occurred in the feedback signal. As noted before, the most useful combinations are the log data action with either INCREMENT or PEAK Event Detector types, and any of the other actions with the THRESHOLD or BREAK types.

Setting the Event Detector Data Log Action

Finally, the Data Log Action Command 130 should be used to set the desired synchronizing action for data log control.

Activating the Event Detector

When all the above commands have been issued, the Event Detector is fully defined and can be put to the active state with the State Command 125 with the parameter set to ON.

Chapter 8
User State Storage

Outline

- Description . . . . Page 8-2
- Parameter Defaults . . . . Page 8-3

During the course of operating the Model 8500, users will enter operating parameters and make menu selections that can be saved into the system's non-volatile memory, so that the system does not need to be set up all over again after it is turned off. This chapter describes what can be saved to memory, and how to save it.

Description

The Model 8500 is provided with non-volatile Random Access Memory (RAM) which prevents the loss of user-selected parameters in the event of a system power loss. All the system parameters, referred to as the System State, are saved in this RAM and restored at power up, with some exceptions which are detailed in the next Section "Parameter Defaults".

The non-volatile RAM is large enough, however, to hold more than one copy of the System State. These extra copies are called User States and are snapshots of the System State at some instant in time.

You have four User States available. While they are distinguished numerically in the command set as States 1, 2, 3, and 4, each can be identified by a descriptive, six-character name. This name is presented on the Front Panel as an aid in remembering the relevance of each state. You can edit this state name at any time.

When you perform a User State Save, a snapshot of the current System State is placed into the selected User State area. Performing a User State Restore overwrites all the current parameters with either the values that were snapshot at the time that User State was stored or with defaulted values as detailed in the next Section "Parameter Defaults".

Parameter Defaults

When the testing system powers up or a User State Restore is performed, several parameters are restored to a default state and not to the state that they were in when the User State Save was carried out. The most common reason for this is to maintain the testing system in a safe condition.

For example, the Waveform Generator state defaults to OFF. Consider a state stored with the Waveform Generator running. This state might then be restored at a time when the system setup was not safe for that particular waveform to run again. Thus, restoring the running state to the Waveform Generator would result in a dangerous condition. Defaulting the Waveform Generator state to OFF ensures that you have a chance to review the setup parameters and to remind yourself what conditions are required for the safe operation of that test.

Another safety-related reason is data integrity. During the time that the sensor conditioner is being restored with hardware setup conditions and calibration values, the sensor feedback data is not valid and therefore is not safe for Limit Detection, Event Detection, or machine control. In fact, the current transducer could very well be different from the one installed when the User State was saved. It is for this reason that the actuator defaults to OFF during a State Restore. Similarly, only the position calibration is automatically restored to the calibrated state. Other transducers require a conscious decision by the user to use the old calibration data via the Front Panel Calibration Restore function. This function is, of course, only available if the transducer is the same as the one plugged in at the time the User State was stored.

Table 8–1 details the various parameters that have a default state upon restore, their command numbers and their default states.

Table 8–1. System Parameter Default States

COMMAND NAME	COMMAND NUMBER	DEFAULT STATE
Ramp Generator Control/Status	1	OFF
Set Level	3	Current position
Loop Error Event Detector Control/Status	17	OFF
Digital Inputs Event Detector Control/Status	25	OFF
Segment Counter Event Detector Control/Status	34	OFF
Load Protect Mode Control/Status	44	OFF
Random Buffer	46	Empty
Same Mode Transfer Type	54	Transfer to current feedback level
Sample Data Playback Buffer	55	Empty
Zero Suppression State	116	OFF
Limit Control/Status	121	OFF
Sensor Event Detector Control/Status	125	OFF
Limit Pre-Programmed Buffer	138	Empty
Transducer Over-Range Protection	139	ON for load cells, OFF for all other transducers
Transducer Self-Compensation Control/Status	148	OFF
Waveform Generator Control/Status	200	OFF

Table 8-1. System Parameter Default States (continued)

COMMAND NAME	COMMAND NUMBER	DEFAULT STATE
Cycle Counter Event Detector Control/Status	212	OFF
Constant Amplitude State	216	OFF
Control Mode	300	Position control
Calibration status (Note 1)	311	Calibrated for position control only, others dependent upon transducer - See Note 1
Control Status (Note 2)	312	Dependent upon transducer - See Note 2
System Stop State	314	Current state
Data Logging Commands	316 through 319	Current state
Event Detector Pre-Programmed Buffer	322	Empty
Limit Lock	326	OFF
Auxiliary Data Logging Channel Signal Select	328	Current state
Next Mode	500	Position

NOTES

1. Calibration status - For the position channel, calibration is restored if it was calibrated when the user state was saved. For all other channels, calibration will go to "Uncalibrated - old data" if the channel was calibrated with the same transducer when the state was saved. If the transducer is different, then calibration will go to "Uncalibrated - no old data".

2. Control status - Always goes to "Enabled" for Instron standard recognized transducers. For a user transducer, the status goes to the previously defined value.

Chapter 9
System Hardware

Outline

- Corporate Manifold and the Docile Mode. Page 9-2
- Analog Monitor Outputs . . . . Page 9-19
- Board Swapping Hints . . . . Page 9-21

There are certain hardware features of the Model 8500 system that may not be readily understood by some users. This chapter describes some of these features and how to use them.

Corporate Manifold and the Docile Mode

Introduction

The Model 8500 uses a new design of hydraulic manifold unique to Instron which provides improved performance in two areas:

- Very low bumps when transferring from the Actuator High or Actuator Low states to Actuator Off
- A "Docile Mode" or Low Pressure mode in which the loads that can be applied to the specimen are restricted, and the maximum velocity of the actuator is limited.

The following section is a guide to how this manifold works, the various transitions which can occur when using the Model 8500 Control Panel (frame) controls, and the theory behind setting up the Docile Mode.

Hydraulic Schematic of the Corporate Manifold

The "corporate" manifold is so-named because it was specifically designed to be used on all Instron servohydraulic load frames world-wide. It differs from conventional manifolds because these simply remove the hydraulic pressure when the manifold is shut off. Figure 9-1 shows the hydraulic schematic of the corporate manifold.

The schematic shows a servovalve with its output ports C1 and C2 connected to the two sides of the piston of an actuator. The significance of the corporate manifold is the addition of the load relief valve shown between ports

C1 and C2. This valve has a pilot which, when pressurized, forces the load relief valve to be closed. When closed, the manifold works in the normal way when full pressure is available on the incoming Pressure line.

However, when the load relief valve is open (i.e. it has no pilot pressure) it provides a shunt for the flow from C1 and C2 to Return. This flow through the load relief valve in either direction can only develop relatively small pressure drops across the valve, and hence across the actuator, and this defines the pressure available to move the actuator. When the servovalve has no drive and is perfectly centered, there is no differential flow be-

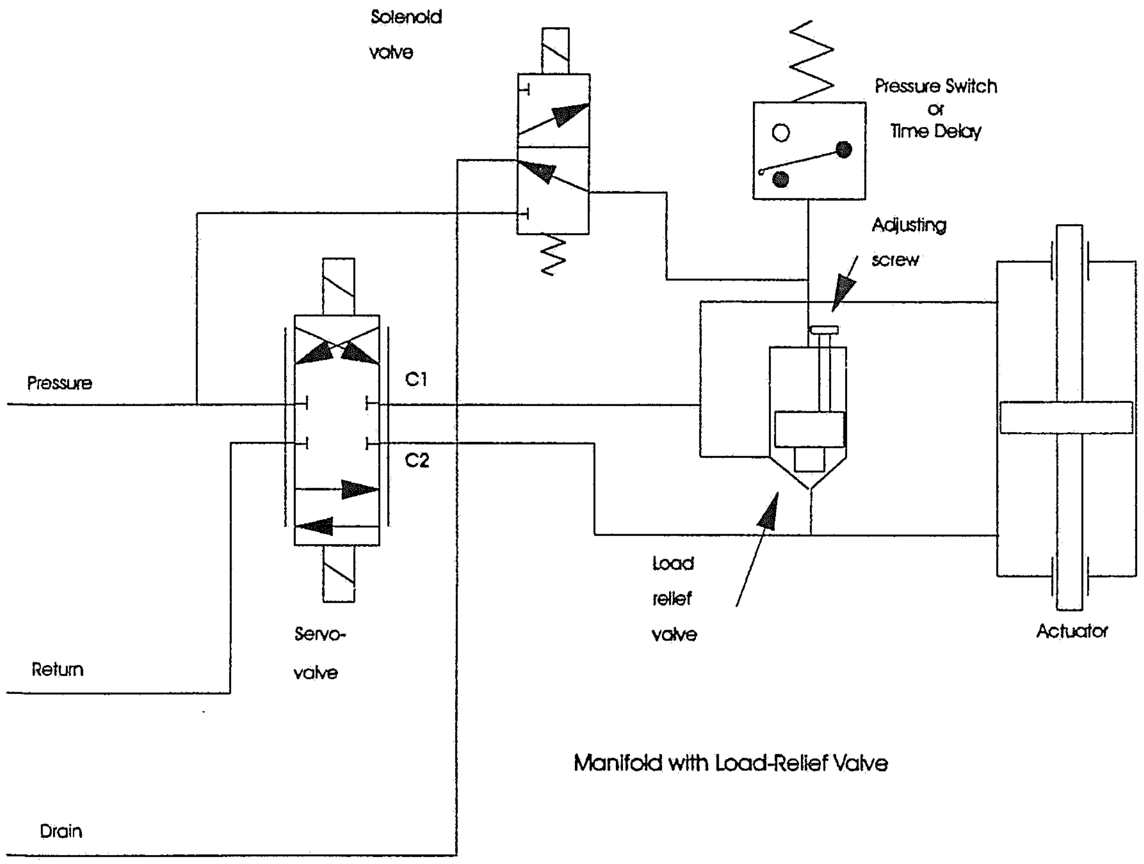


Figure 9-1. Manifold Schematic Diagram

tween C1 and C2. If the weight of the piston plus the lower grip exceeds the static friction, the actuator may drift downwards because of the shunt between the two sides of the actuator when the relief valve is open. This is normal and is the difference from previous manifolds without the relief valve.

There are three states of the corporate manifold:

HIGH - The load relief valve is closed and full pressure is available to the actuator to move it in either direction.

LOW - The load relief valve is open; when the servovalve moves, most of the flow generated is shunted by the relief valve and hence the actuator can only develop small loads as determined by the available pressure drop. Also, since the flow available for the actuator is now limited, its slew rate is reduced. This is called the DOCILE mode.

OFF - The load relief valve is open, and in addition, the servovalve drive coil is electrically short-circuited. The valve goes to its mechanical null, and only small residual differential flow is available, whose pressure drop is insufficient to move the actuator. Note that full pressure is still being applied to the servovalve even in Actuator OFF; it just cannot develop any load.

The major advantage to this scheme is in bumpless turn-offs. When the user requests a transition from actuator HIGH to actuator OFF, the electronics sequence through the Actuator LOW state during the transition. Thus, firstly, the load is removed from the specimen by opening the load relief valve, and then, when this has happened, the servovalve is shorted. Extremely smooth

Table 9-1. Corporate Manifold Transition States

TRANSITION FROM/TO	IMMEDIATE EFFECT	EFFECT ON COMMAND	EFFECT ON INTEGRATOR	EFFECT ON SERVOVALVE LIMITS
OFF -> LOW	Unshorts the servovalve	Unshorting the servovalve causes command to equal the current feedback.	Unshorting the servovalve turns the integrator on.	Remains at the low pressure state.
LOW -> HIGH	Turns on drive to solenoid valve which applies pressure to open the release valve	Turning on the drive causes command to equal the current feedback.	Turning on the drive causes integrator to go to stored value when last in high pressure (default is the static integrator setting).	Turning on the drive causes the valve limits to go to the high pressure state.
OFF -> HIGH	Unshorts the servovalve and simultaneously turns on drive to the solenoid valve.	Unshorting the servovalve causes command to equal the current feedback.	Turning on the drive causes integrator to go to stored value when last in high pressure (default is the static integrator setting).	Turning on the drive causes the valve limits to go to the high pressure state.
HIGH -> LOW	Removes the drive to the solenoid.	No effect.	No effect.	Removing the drive causes the valve limits to go to the low pressure state.

Table 9-1. Corporate Manifold Transition States (continued)

TRANSITION FROM/TO	IMMEDIATE EFFECT	EFFECT ON COMMAND	EFFECT ON INTEGRATOR	EFFECT ON SERVOVALVE LIMITS
LOW -> OFF	Once the pressure switch indicates the release valve has no pilot pressure (normally this is already true), shorts servovalve.	At the moment the servovalve is shorted, sets command equal to current feedback, and turns off waveform generator, if it is on.	Shorting the servovalve causes the integrator to be turned off.	Remain at low pressure state.
HIGH -> OFF	Removes the drive to the solenoid valve, and when the pressure switch indicates the release valve has no pilot pressure, shorts the servovalve.	At the moment the servovalve is shorted, sets command equal to current feedback, and turns off waveform generator, if it is on.	Shorting the servovalve causes the integrator to be turned off.	Removing the drive causes the valve limits to go to the low pressure state.

transfers to zero load on the specimen have been demonstrated using this scheme.

Action of the Model 8500 Control Panel

The following table is intended to clarify the various states of the hydraulics in a Model 8500 System with a Corporate manifold. These states are determined manually by the user with the ACTUATOR OFF, LOW and HIGH buttons on the Frame Control Panel, but transitions from HIGH to OFF can also be caused by a fault condition detected in the Tower Console.

The changes in states are initiated by pushing one of the buttons on the Control Panel. The actual transitions which result are related to:

1. A signal which causes a switch to short-circuit the servovalve coil
2. A current drive to a solenoid valve which supplies hydraulic oil to the pilot stage of the load release valve across the C1-C2 ports of the actuator
3. A pressure switch which senses the pressure in the pilot stage of the load release valve. When the current is applied to the solenoid valve, it typically takes 50-70 msecs before the pressure switch sees a change, and this occurs almost simultaneously with the opening of the load release valve.

Note *On some models of the manifold, the pressure switch is replaced by a time delay circuit. This allows sufficient time for full-pressure changes to be sensed by the Model 8500 Controller.*

When these signals occur, they have an effect on the following parameters in the Model 8500 Control System:-

- The Model 8500 command value in whatever control mode it is in
- The state of the integrator in the control loop
- Which of two possible sets of servovalve drive limits are operational. These are limits on the maximum positive and negative drive signals which can be applied to the servovalve. The Low Pressure servovalve drive limits are used to limit the flow in the Docile mode, and the High Pressure limits are set to 100%. Limiting the maximum flow which can occur in the Docile (Low Pressure) mode limits the pressure drop, and hence the load, which can be developed by the actuator.

Shorting the Servovalve with the Corporate Manifold

It important to realize that in all cases where the actuator is OFF, the servovalve is shorted. This is because with the new Corporate manifold, pressure is always present at the actuator, but the load release valve prevents significant loads being built up in the docile mode. When there is no drive to the servovalve, it is important that it be at its null condition or the actuator could drift in position.

Setting up the Docile Mode

Introduction

Setting up the Docile Mode is not difficult when the theory behind its operation is understood. Referring to Figure 2-1, the objective is to set the adjusting screw on the load relief valve (which determines its constriction when open) so that in combination with the positive and negative low pressure valve limits, the maximum load which can be applied in tension or compression while in the Docile Mode is only about 2% of the rating of load string. The normal procedure is to set the minimum valve limit, which governs motion in the compression direction, to a nominal value between 10 and 50%. A setting for the adjusting screw is then found so that the maximum compression force which can be delivered to a specimen when the servovalve is at this limiting drive is about 2% of the load rating. Finally, the maximum drive limit, which governs motion in the tension direction, is set so that a maximum tensile load also of about 2% of the load rating can be delivered.

This procedure is described in more detail in the Model 8500 Operating Instructions Manual M11-98500-1, in the Sections "Adjusting Servovalve Null" and "Servovalve Drive Limit Adjustment" in Chapter 6. However, there are special situations when it does not work well, and in these cases the alternative is given here.

When the Standard Docile Mode Set-up Procedure Does Not Work

The original set-up procedure was derived from the set-up procedure for Model 2180 analog system. However, for more difficult configurations such as low-friction actuators, low-force actuators, and dual servo-valve manifolds, it may be necessary to change the procedure slightly. The problems occur when there is a large servovalve on a small actuator.

Principle For Table-mounted Actuators

The first priority is to ensure the actuator cannot move UP under Actuator-Off conditions. The second priority is to set up an acceptable Docile Mode compression force, and the third priority is to achieve an acceptable tensile force.

The actuator may move when in Actuator-Off, with the servovalve shorted, because there is still pressure on both sides of the actuator. The load relief valve is open, but a mechanical offset in the servovalve may result in sufficient flow across the relief valve to generate a large enough pressure drop to overcome friction and move the actuator. This is particularly possible if the servovalve is large and the actuator stall force and/or friction is low.

The maximum specified drift in the servovalve mechanical null is about 3% of rated flow. So, if we set up the system and ensure that even with as much as 6% servovalve drive, the actuator cannot move in the compression direction, then we have ensured that whenever the servovalve is shorted in Actuator-Off, the mechanical null cannot drift enough to move the actuator.

Checking If There Is A Problem

Firstly, perform the normal Docile Mode set-up as described in Chapter 6 of Manual M11-98500-1.

Then press the FUNCTION key, then press K4 under INSTRON SERVICE. Press K1 under CONTINUE, and then K4 under SERVO LIMITS. Finally press K1 to select the LOW Servovalve Drive Limits. The display will look like:

low drive			**MAX**	**MIN**
limits		**12.0**	**-15.0**	**return**
●	●	○	○	○

For the Compression valve drive limit, select the Minimum Drive Limit by pressing the K4 key under MIN. The next display appears:

PRESENT MINIMUM DRIVE LIMIT = -15.0

Enter new value

● ● ● ● ●

Set the minimum drive limit on the numeric keypad to -6.0% Turn on the hydraulic pressure and set the Control Panel to Actuator Low (Docile mode), in Position control.

Using the UP jog button, try to move the actuator in the upwards direction. If it can move, you have a problem and will need to use the following modified procedure.

Step-by-Step Procedure

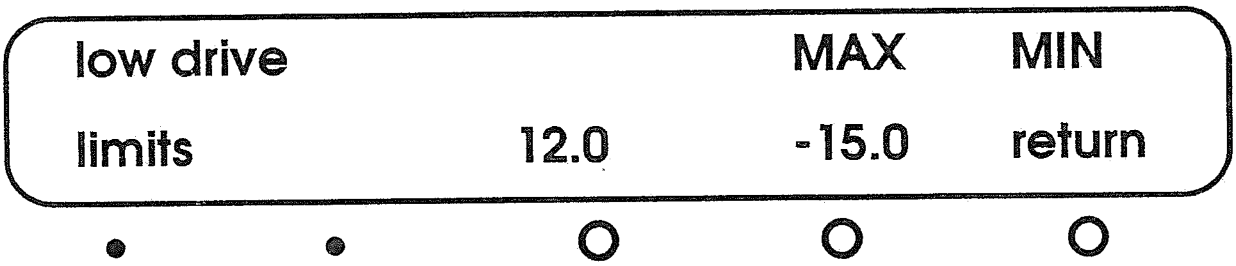
This procedure is somewhat similar to that in Manual M11-98500-10.

Servovalve Null

a. Adjust the servovalve null mechanically. Use the procedure described in the "Servovalve Null Adjustment" Section of the Manual to adjust the servovalve null.

Shunt Valve Orifice

b. Adjust the Shunt valve orifice for -6% threshold. The shunt valve orifice adjustment is a screw with lock-nut located on the side of the servovalve manifold. It is not possible to turn the adjustment screw with hydraulic pressure applied, so a small turn of the screw is made with the pressure off, and then the effect checked with the pressure on. Loosen the lock-nut and turn the screw in fully, then back it out about 1/8 turn to begin. There should be no specimen installed. The set-up is done in Position control, with a reasonable value set for Proportional Loop Gain. Turn Dither on with a small value, typically below the amplitude where it can be heard.

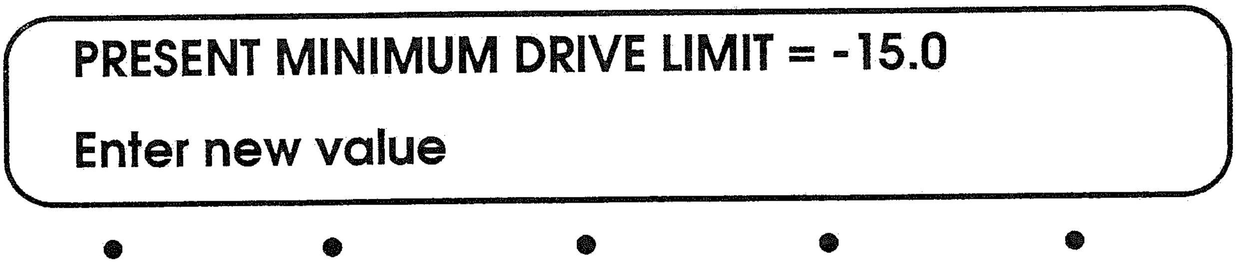


low drive MAX MIN

limits 12.0 -15.0 return

● ● ○ ○ ○

c. Press the FUNCTION key, then press K4 under INSTRON SERVICE. Press K1 under CONTINUE, and then K4 under SERVO LIMITS. Finally press K1 to select the LOW Servovalve Drive Limits. The display will look like this:



PRESENT MINIMUM DRIVE LIMIT = -15.0

Enter new value

● ● ● ● ●

d. For the Compression valve drive limit, select the Minimum Drive Limit by pressing the K4 key under MIN. The next display appears:

e. Set the minimum drive limit on the numeric keypad to -6.0% Turn on the hydraulic pressure and set the Control Panel to Actuator Low (Docile mode), in Position control.

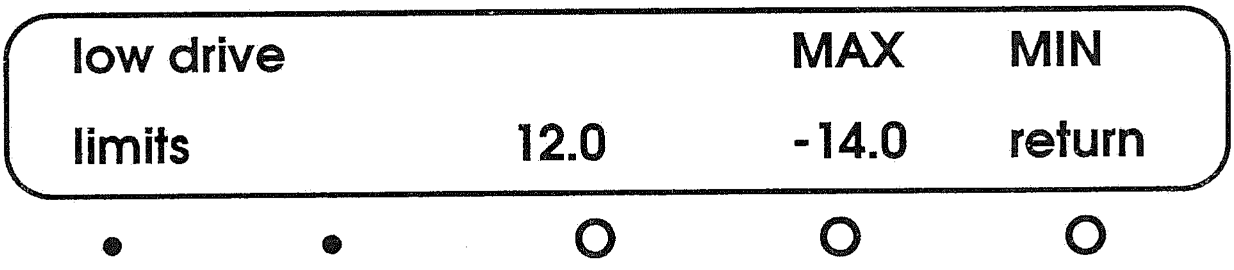
f. Using the upper jog button, try to move the actuator in the upwards direction. If it can move, decrease the minimum drive limit from -6% to -3% and see if it still can move. If it can not move, increase the drive limit to -10% or higher. The object is to find the threshold valve limit at which the actuator just begins to move, and then adjust the Shunt Valve Orifice screw to make this -6%.

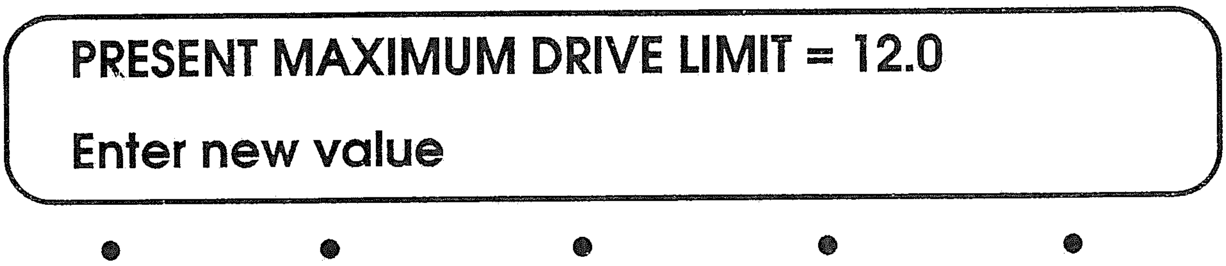
g. If the actuator can still be moved at less than -6%, you need to open the orifice by turning off the pressure and backing the screw out slightly. If the actuator cannot move above -6%, turn off the pressure and turn the screw in very slightly. You will have to turn the pressure on and off a few times until you get the threshold of jogging in the UP direction at -6% ±1%.

h. Finally, screw in the lock-nut and verify the compression threshold is still about -6%.

Minimum Drive Limit

i. Adjust the Minimum Drive Limit for the required compression stall force. Place a block of wood or other suitable compression specimen between the actuator and the load cell. While still in the Low Pressure mode, increase the Minimum Drive Limit to -10% so that the actuator can be jogged up easily, and move it up against the specimen and measure the compression stall force. Increase the minimum drive limit as necessary to achieve the required stall force in compression, typically 2% of the stall force of the actuator or less.


low drive MAX MIN
limits 12.0 -14.0 return
● ● ○ ○ ○


PRESENT MAXIMUM DRIVE LIMIT = 12.0
Enter new value
● ● ● ● ●

Maximum Drive Limit

j. Adjust the Maximum Drive Limit for the required tensile stall force. Suppose you found that -14% was a suitable value for the Minimum drive limit. The Low Drive Limits display will now look something like this:

k. Now press K3 to select the Maximum drive limit, to get this display:

l. Mount a specimen in the grips, and still in Low Pressure, move the DOWN jog button and measure the tensile load applied to the specimen. If it is too high, reduce the maximum drive limit. Typically it would be set to the same tensile stall force value as the compressive stall force previously set. You may be able to reduce the drive limit all the way to zero if friction is low enough, at which point the force on the specimen is substantially the mass of the actuator piston and the grip.

Dual Servovalve Manifolds

It is important that the *larger* servovalve in dual servovalve configurations be set up first according to the above procedure, to ensure that the actuator cannot move in Actuator-Off when it is active. When the smaller servovalve is active, it may be necessary to increase the Minimum and Maximum valve drive limits to obtain enough flow to move the actuator when jogging. However, if this is done, it is important to remember to reset the limits to the previous values when the larger valve is used again, because otherwise the stall forces will be larger than expected.

Crosshead Mounted Actuators

If the actuator is mounted in the crosshead, different criteria apply. The actuator will always drift down under its own weight when in the ACTUATOR OFF condition, as oil flows through the load relief valve. Now the objectives in the Section "Principle for Table-Mounted Actuators" on page 9-10 may be re-written:

"The first priority is to ensure the actuator cannot move UP under Actuator-Off conditions. The second priority is to set up an acceptable Docile mode tension force, and the third priority is to achieve an acceptable compression force".

Thus the procedures are very similar to those written above, except the signs are reversed. Verify that with a maximum valve drive of +6% the actuator cannot move up in the docile mode, adjusting the relief valve adjusting screw as necessary. Then adjust the maximum valve limit so that a tensile load of about 2% can be achieved. Then adjust the minimum valve limit so that a maximum compression load of 2%, or the weight of the piston plus the upper grip, whichever is greater, can be achieved. Note that the minimum valve drive limit may numerically be considerably less than the maximum valve limit, because of the addition of the weight of the piston and grip.

Use With Non-corporate Manifolds

With previous manifolds, and some that may occur in retrofits, the manifold has no load release valve, and it has a solenoid valve in the pressure line before the servovalve. This solenoid valve can be driven with the current that would have gone to the solenoid valve for the release valve in the Corporate manifold. There are two conditions to consider:

1) If there is no pressure switch, the input to the Tower Rear Door should be left open, simulating a permanent Low Pressure condition for the switch. OFF - LOW would unshort the servovalve, and LOW - HIGH would apply pressure to the servovalve. Note that the servovalve limits would be permanently in the Low Pressure state, which should be set to 100%. Avoid a manual transition directly from HIGH to OFF, since the servovalve will immediately short while there is still pressure on the actuator, and a large load transient can occur. Using the LOW condi-

tion as an interim step allows pressure to be removed before the servovalve is shorted.

2) If there is a pressure switch, it can be used as if it were the pressure switch on the load release valve to protect the HIGH - OFF transition by not permitting the servovalve to be shorted until a suitably low pressure has been achieved.

Example On Model 8501 With Grips

Below is shown, in Figure 9-2, data from a Model 8501 frame in the Model 8500 Development Laboratory, showing how the compressive and tensile stall forces

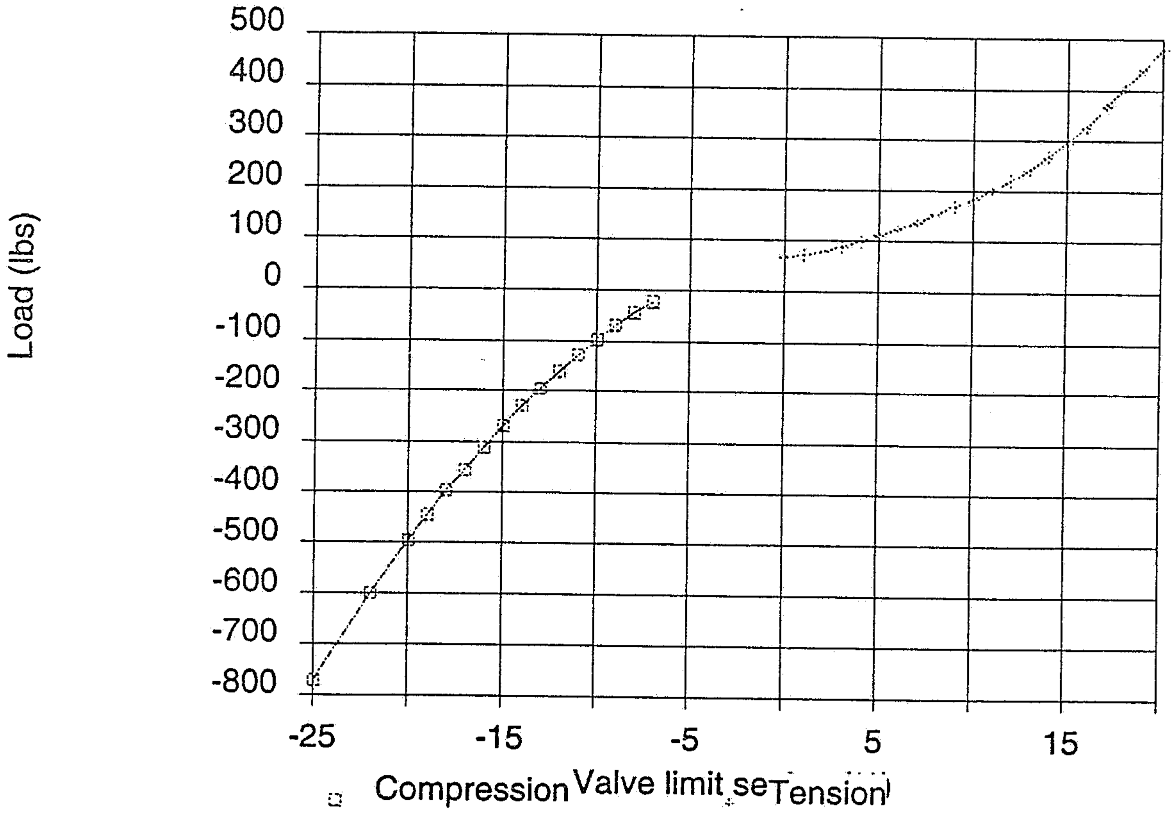


Figure 9-2. Example of Docile Mode Stall Force vs. Limit Setting

vary with the valve limits chosen. Note the "dead zone" around zero, where the available actuator forces cannot overcome friction, and that zero compressive force is developed around 6% valve drive.

Analog Monitor Outputs

The Model 8500 uses a separate high-resolution, high-accuracy 14-bit DAC to drive each of the four analog monitor jacks, – A, B, X, and Y. The outputs are calibrated, with a full-scale of ±10Vdc. Each output can be digitally offset and scaled, to magnify any portion of the feedback or command waveforms. In addition, other signals such as peaks, means, valve drive, and so on, can be switched onto any output, even though most do not exist in analog form anywhere inside the Model 8500 system. In earlier versions of the Model 8500, only one 12-bit "Monitor DAC" was available for this purpose, and it permitted only digital scaling, without digital offset.

The usefulness of digital offset and scaling is directly related to the wide dynamic range of signals that exists in the Model 8500. You can offset the analog output to the exact region of interest, and then easily magnify the output digitally so that 10 volts represents the desired number of engineering units. This results in the full 14 bits of DAC resolution over any portion of the signal's range. As all of this is done digitally, the autoranging built into the Model 8500 makes the quality of the analog outputs very high. Furthermore, the offset and gain controls of the actual scope or recorder never need to be adjusted when the output signal is switched to a different line; the output data is always calibrated if the internal binary signal is calibrated.

As a reference point, the earlier version of the Model 8500 used pure, unranged analog signals for the A, B, X, Y outputs. All scaling had to be done at the scope or recorder, and calibration was done via trimpots on the rear door of the Tower. The Model 8500 Plus has no more trimpots. The only place that these “raw” analog signals exist now is on the unswitched ANALOG OUTPUTS D-connector. These are made available for external data acquisition equipment.

Board Swapping Hints

Swapping Master Dynamic Controller (MDC) and Sensor boards in the field, for reasons of maintenance, repair, or upgrade, is quite straightforward; here are some hints:

Master Dynamic Controller Board

If you wish to save the position calibration, it is important to transfer the non-volatile RAM chip to the replacement board.

Caution

Turn off all electrical power to the system before replacing printed circuit boards. Failure to do so may seriously damage components on the boards.

(a) Turn off the power at the Tower Rear Door.

Caution

Printed circuit boards are very sensitive to electrical static, which can permanently damage them. Before handling boards, first discharge yourself by touching any exposed bare metal on the Tower cabinet. Do not touch components on the board, especially integrated circuit chips. Do not touch the pins of board connectors.

(b) Remove the old MDC card, and, before doing anything else, make a unique mark on the non-volatile RAM chip on the board so it won't get mixed up with another. It is a large dual inline socketed package, labeled RAMified TIMEKEEPER.

(c) Remove the replacement MDC board from its package; transfer the old non-volatile RAM chip to the replacement board; mark the non-volatile RAM chip from the replacement board "BLANK" and place it in the old MDC board.

(d) Insert the replacement MDC board and turn the power back on. The previous machine state will be restored.

Sensor Conditioner Board

To replace a sensor board, turn off the power and swap the board. *You must then do a new calibration for that channel.* Do not restore the old calibration, because the calibration process measures and saves all the offsets unique to a particular board. For Load and Strain this is usually simple; just do a new auto-calibration. For Position, you will have to go through a complete manual position calibration, as described in the Installation Manual.

Chapter 10
Multi-Axial Systems

Outline

- Introduction .... Page 10-2
- Command Synchronization .... Page 10-3
- Cross Compensation .... Page 10-5

Several Model 8500 Control Systems can be used in tandem to operate multiple channels in a multi-axial system. Such multi-axial systems might be structures systems that test automotive suspension systems in several simultaneous directions, or in structures loading systems that load a device in many axes at once. This chapter describes how a multi-axis Model 8500 Structures system is synchronized, and how cross-channel compensation is accomplished.

Introduction

For certain special applications, the Model 8500 is available in multi-axial configurations. These systems are commonly used where more than one servohydraulic actuator is included in the system. Such applications might include a structure, such as an aircraft wing, automotive suspension systems, or other large structures. A multi-axial system might also include tension-torsion testing of small components, such as certain types of tubing, where torsional loading as well as axial loading is required.

Each additional axis has its own associated Front Panel Controller and Tower Console. All axes are identical, and can function independently of the others. This means that all of the axes are operated in the same way, and that all descriptions in this manual and all of the other manuals for the Model 8500 apply equally to every axis.

In order to have the separate axes operate smoothly together, however, several inter-axis features are built into the Tower Console. These features are the subject of this chapter, and details of operation are described in Chapter 7 of the Model 8500 Operating Manual, M11-98500-10. Obviously, if your Model 8500 System has only one axial channel, this chapter does not apply to your system.

This chapter discusses technical details of the extended features for the Multi-Axial System. The first section discusses waveform generation – how multi-axial synchronization, or slaving, of waveforms works, and relates to the single axis waveform generation as described in Chapter3. The second section covers transducer cross-compensation, and includes a table of typical testing applications.

Command Synchronization

This section describes waveform generation synchronization in the multi-axial system. One or more axes may be slaved to one master axis so that the waveform generator of all the axes are controlled simultaneously.

Cyclic Waveform Generator

The Cyclic Waveform Generator can operate in one of three modes: the Free mode, the Slaved mode, or the Slave Locked mode. When the mode is Free, the waveform generator operates independently, and can be designated as the Master of another channel. When in the Slaved mode, however, the waveform generator state transitions are controlled primarily by the Master Waveform Generator. Certain conditions (event actions) on either the slave axis or the master axis will cause a Slave Waveform Generator to enter the Slave Locked state. Generally, any event action (hold, stop, or mode transfer) on either axis that is not designated as a system action, will cause the Slave Waveform Generator to stop, and it will enter the Slave Locked state. The only way to clear this state is to go to the Free mode.

In addition to synchronization of slave state transitions with those of the master, argument generation is locked with the master. Referring to Figure 10-1, we see that the frequency of the slave waveforms is proportional to the master waveform frequency, scaled by the frequency ratio parameter. The argument, as is true for the master axis, is a variable that increments at the rate determined by waveform frequency. Before shaping this variable into the selected waveform shape (sine, triangle, etc.), a phase shift is added to either advance or delay the phase of the slave

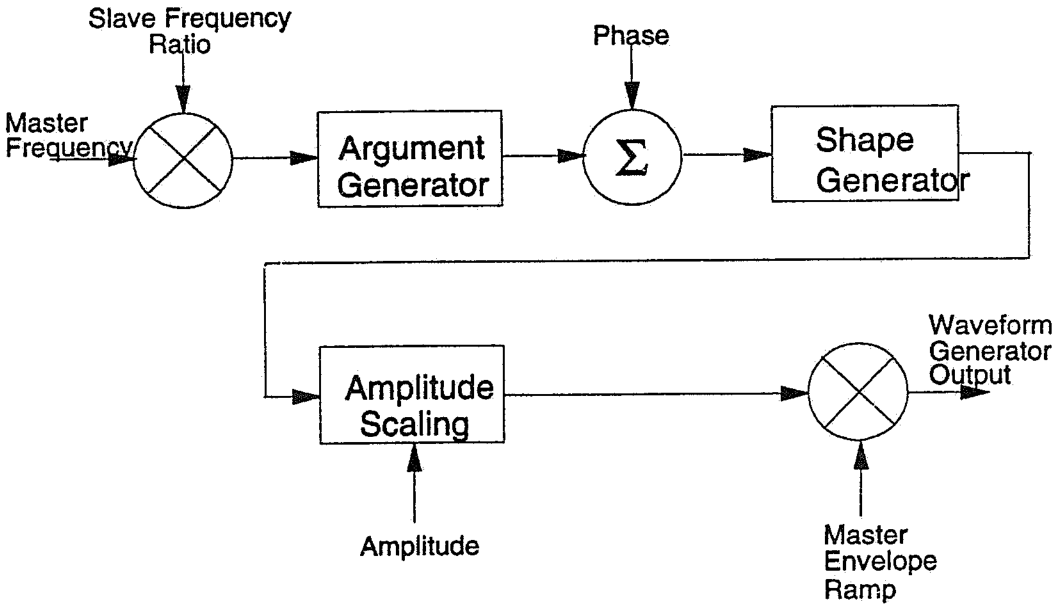


Figure 10-1. Multi-Axial Cyclic Waveform Generator

waveform in relation to the master. Following shaping of the argument and amplitude scaling, the waveform is multiplied by the master envelope ramp so that the slave waveform envelope is perfectly synchronized to that of the master axis.

Ramp Generator

Like the Cyclic Waveform Generator, the Ramp Generator is enhanced with slave states to support multi-axial command synchronization. While the Ramp Generator is in the slave mode, it tracks the state of the master Ramp Generator so that events like start, hold, finish, etc., happen at the same time. In addition, the basic state diagram of the Ramp Generator (Figure 3-6) is expanded to include a start delay. When the master ramp starts, the slave enters the delay state, where it remains until the user-settable delay time has expired. It then goes to the running state and starts to generate ramps as usual.

Cross Compensation

Cross-Compensation allows linear compensation of any transducer signal in the system by any other single transducer signal. The compensation is performed digitally in realtime on a sample-by-sample basis at the 5 kHz sample rate. If we let X represent the data stream for a channel to be compensated, then the compensated output, X′, is given by the equation:

$$X' = \frac{(X + A \cdot Y)}{2} - C \qquad (1)$$

where Y is the data from the compensating channel, A is the user-defined scale factor, and C is the user-defined compensation offset. The division by two is optional and provides an averaging function.

The scale factor A can range from -1.0 to 1.0, or minus full scale to plus full scale of the source channel. The resolution is 0.00003, or 0.003% of full scale.

There is a time delay of one sample period between the feedback and the control loop when Cross-Compensation is active. The reason for this is that the data samples for X and Y do not necessarily occur at exactly the same moment in the sample period. Waiting until the next sample period to broadcast the data ensures that both X and Y data have been sampled.

An Example of Using Cross-Compensation

By properly setting the compensation parameters, a variety of useful applications can be realized. Table 10-1 in the next section gives a summary of some common uses.

Note that in calculating the scale factor A, it is often necessary to factor in the full scale ratio of the two channels involved to properly normalize the values before they are scaled and added. This is because the compensation takes place on the internal, fractional values, not the values in engineering units.

To illustrate this point, consider an example of correcting for load frame stiffness. In this application, it is desired to correct the displacement reading of the actuator to remove the deflection of the frame under load. The following variables are relevant:

K_f = frame stiffness, including load cell

F_p = full scale position

F_l = full scale load

x = position measurement in internal fractional units

x' = compensated position in internal fractional units

p = position in engineering units

p' = corrected position measurement

y = load measurement in internal fractional units

l = load in engineering units

d = frame deflection to be compensated for, a function of load

The following relationships hold between values in internal units and engineering units:

$$p = F_p x$$

$$l = F_l y$$

$$p' = F_p x'$$

Assuming that the frame behaves as a linear spring, then the deflection of the frame due to the imposed specimen load is given by:

$$d = \frac{l}{K_f}$$

The corrected position p′ is given by the measured position minus the frame deflection, so

$$p' = p - d = p - \frac{l}{K_f}$$

By employing substitution, the expression can be stated with p′ a function of x and y, the measured position and load variables, respectively, as:

$$p' = F_p x - F_l \frac{y}{K_f} = F_p (x - \left(\frac{F_l}{F_p K_f}\right) y)$$

It follows that:

$$x' = x - \left(\frac{F_l}{F_p K_f}\right) y \qquad (2)$$

This equation is in the form of equation (1) in Section 10.2. It can be seen now that the variable x′ can be obtained by substituting the scale factor A, as given by :

$$A = -\frac{F_l}{F_p K_F} \qquad (3)$$

in the compensation equation (1), turning the averaging off (no division by 2), and setting the constant C to zero.

Table of Cross-Compensation Applications

Table 10-1 is presented below with example applications of Cross-Compensation. For each application, the table defines the signal and source channel, along with the scale factor A, the offset factor C, and whether averaging is on or off. The table is meant only as a guide, and not a definitive source. Many of the applications have possible other factors involved, depending on the particulars of the user test setup. It is left to you to make sure the compensation factors used are correct for your test setup.

Some special symbols are used in the table and are defined as:

K_f = frame stiffness, including load cell

F_p = full scale displacement of actuator or extensometer, as appropriate

F_l = full scale load

F_{pr} = full scale pressure

A = specimen cross-sectional area

A_e = effective area of fixturing extending into pressure chamber

G = gauge length of extensometer

E = Young's modulus of specimen material

It is important to note that Cross-Compensation allows linear compensation only. For many of the applications below, a linear compensation factor may not be sufficient. For example, in the mechanical strain at temperature application, the thermal coefficient value is often not constant with temperature, meaning that a non-linear compensation is required.

Table 10-1. Examples of Cross-Compensation Applications

Application	Comp. Signal	Comp. Source	Comp. Factor	Comp. Offset	Averaging
Strain Averaging	Strain 1	Strain 2	1.0	0.0	On
Strain Difference	Strain 1	Strain 2	1.0	0.0	Off
Frame Stiffness Correction	Position	Load	$-\frac{F_l}{F_p K_f}$	0.0	Off
Tension-Torsion Load Cell Crosstalk	Load	Torque	- Crosstalk Factor	0.0	Off
Plastic Strain	Strain	Load	$-\frac{F_l G}{F_p A E}$	0.0	Off
Digital Zero Offset	any	same	0.0	Desired Offset	Off
Mechanical Strain at Temp.	Strain	Temp.	- Thermal Coefficient	- Initial Temp. times Thermal Coefficient	Off
Pressure Vessel Load Compensation	Load	Pressure	$-A_e\left(\frac{F_{pr}}{F_l}\right)$	0.0 (if gage pressure is used)	Off

Appendix A
Choosing Code Resistors

Outline

- Choosing Calibration And Recognition Code Resistors .... Page A-2
- Choosing the Recognition Resistor - Theory............................ Page A-10
- Instron Calibration Service .... Page A-16

Instron transducers, such as load cells, actuator LVDTs, and extensometers have a unique electronic identification that enables the testing system to recognize it and ascertain it's characteristics. This appendix describes this identification system and discusses the theory of choosing recognition resistors.

Choosing Calibration And Recognition Code Resistors

All standard Instron transducers, such as load cells and extensometers, currently supplied with the Model 8500, contain calibration and recognition code resistors mounted in their electrical connectors. The following sections describe how these resistors work, and tell how to choose resistors for older Instron transducers or user-supplied transducers that lack them.

Schematic of the Instron Transducer Connector

Figure A-1 is the schematic of the transducer connector board built into the transducer connector. The strain gage bridge is connected as shown, and, for user transducers, may be a load cell, extensometer, or individual gages on the test specimen. Each gage resistor has a nominal value R_G. Note that if less than four strain gages are used, the user must supply the bridge completion resistors externally. The board provides mounting for two resistors R_1 and R_2 whose sum forms the recognition code resistance R_{CODE} (see the Section "Choosing the Recognition Resistor – Theory" below). It also provides mounting for resistors R_3, R_5 and a trimmer resistor R_4, whose sum forms the shunt calibration resistance R_{SH}, which is described in the Section "Choosing the Shunt Calibration Resistor" below.

Operation is as follows: When power is applied to the two small relay coils of K_1 and K_2, the contacts of K_1 are closed and the contacts of K_2 are opened. Thus the value of R_{CODE} which is measured will go from zero ohms to the value given by R_{CODE}. The bridge will be

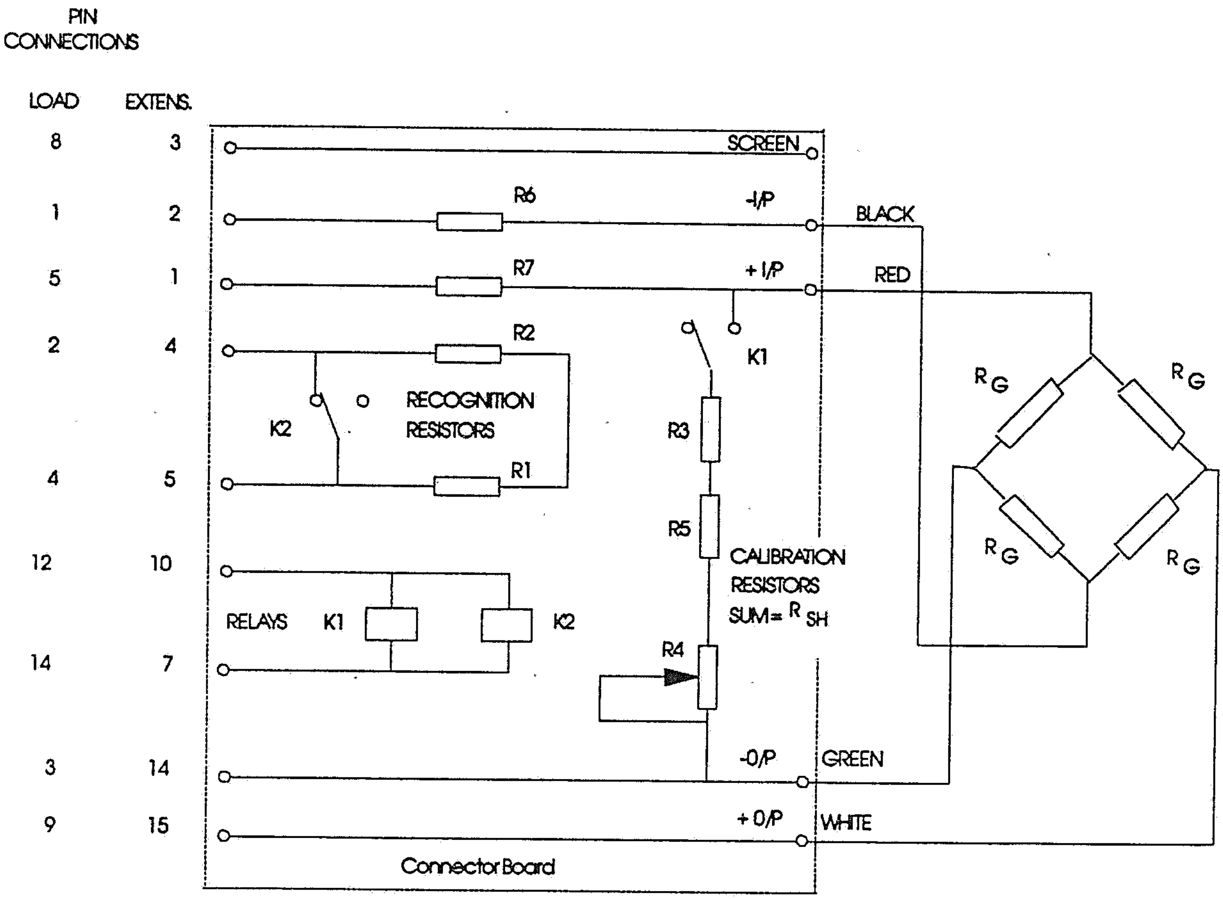


Figure A-2. Transducer Connector Schematic

unbalanced by the added shunt calibration resistance R_{SH}. The resulting bridge output is what is seen by the Model 8500 sensor during automatic calibration, and it must correspond to the given full scale output value of the transducer. The following sections describe how to choose values for R_{CODE} and R_{SH}.

Choosing the Shunt Calibration Resistor

The fractional change in resistance of a strain gauge element is given by:

$$\frac{\Delta R}{R} = K \cdot \varepsilon$$

where K = Gauge Factor,

and ε = Strain.

Consider a bridge circuit with four arms, each with an unstrained resistance R_G. With a total voltage applied across the bridge of *V* volts, the output in the balanced condition $\Delta V = 0$ volts. When one leg of the bridge R_G is now shunted by a calibration resistor R_{SH}, the change in voltage is given by:

$$\Delta V = V \cdot \left\{ \frac{R_G}{2R_G} - \frac{\dfrac{R_G \cdot R_{SH}}{R_G + R_{SH}}}{R_G + \dfrac{R_G \cdot R_{SH}}{R_G + R_{SH}}} \right\}$$

$$= V \cdot \left\{ \frac{1}{2} - \frac{R_G \cdot R_{SH}}{R_G^2 + 2R_G R_{SH}} \right\}$$

$$= V \cdot \left\{ \frac{R_G}{2 \cdot (R_G + 2R_{SH})} \right\} \qquad (1)$$

Calibrating to a Known Sensitivity

If $\frac{\Delta V}{V}$ is known for full scale, then the value for R_{SH} is found from (1) above:

$$\frac{\Delta V}{V} = \frac{R_G}{2 \cdot (R_G + 2R_{SH})}$$

$$\therefore \quad 2R_G \frac{\Delta V}{V} + 4R_{SH} \frac{\Delta V}{V} = R_G$$

$$\therefore \quad R_{SH} = \frac{R_G}{4\frac{\Delta V}{V}} - \frac{R_G}{2} \tag{2}$$

Note that this is independent of how many active bridge arms there are.

Calibrating to a Known Strain, Four Active Elements

The fractional change in output voltage from a strain gauge bridge with four active elements is given by:

$$\Delta V = V \cdot \left\{ \frac{R_G + \Delta R}{2R_G} - \frac{R_G - \Delta R}{2R_G} \right\}$$

$$= V \cdot \frac{\Delta R}{R_G}$$

$$= V \cdot K\varepsilon$$

To calibrate at a given strain ε, we equate ΔV here with that due to the calibration resistor from (1) above, i.e.

$$V \cdot K\varepsilon = \left\{\frac{R_G}{2 \cdot (R_G + 2R_{SH})}\right\}$$

$$\therefore \quad K\varepsilon = \frac{R_G}{2 \cdot (R_G + 2R_{SH})}$$

$$\therefore \quad 2R_G K\varepsilon + 4R_{SH} K\varepsilon = R_G$$

$$\therefore \quad R_{SH} = \frac{R_G}{4K\varepsilon} - \frac{R_G}{2} \tag{3}$$

Calibrating to a Known Strain, Two Active Elements

The fractional change in output voltage from a strain gauge bridge with two active elements is given by:

$$\Delta V = V \cdot \left\{\frac{R_G + \Delta R}{2R_G} - \frac{R_G}{2R_G}\right\}$$

$$= V \cdot \frac{\Delta R}{2R_G}$$

$$= V \cdot \frac{K\varepsilon}{2}$$

To calibrate at a given strain ε, we again equate ΔV with that due to the calibration resistor from (1) above, i.e.:

$$V \cdot \frac{K\varepsilon}{2} = V \cdot \left\{\frac{R_G}{2 \cdot (R_G + 2R_{SH})}\right\}$$

$$\therefore \quad R_G K\varepsilon + 2R_{SH} K\varepsilon = R_G$$

$$\therefore \quad R_{SH} = \frac{R_G}{2K\varepsilon} - \frac{R_G}{2} \tag{4}$$

Calibrating to a Known Strain, One Active Element

The fractional change in output voltage from a strain gauge bridge with only one active element is given by:

$$\Delta V = V \cdot \left\{ \frac{R_G + \Delta R}{2R_G + \Delta R} - \frac{R_G}{2R_G} \right\}$$

$$= V \cdot \left\{ \frac{\Delta R}{2(2R_G + \Delta R)} \right\}$$

$$= V \cdot \left\{ \frac{\frac{\Delta R}{R_G}}{2\left(2 + \frac{\Delta R}{R_G}\right)} \right\}$$

$$= V \cdot \left\{ \frac{K\varepsilon}{2(2 + K\varepsilon)} \right\}$$

To find RSH, equate $\frac{\Delta V}{V}$ with (1):

$$\frac{K\varepsilon}{2(2 + K\varepsilon)} = \frac{R_G}{2(R_G + 2R_{SH})}$$

$$\therefore \quad R_{SH} = \frac{R_G}{K\varepsilon} \qquad (5)$$

Examples

Case (a): You have a transducer, at whose full scale calibration point, the sensitivity is known to be 2.35 mV/V. You wish the calibration relay to give a change in the bridge output of 2.35 mV/V.

Using (2) above, and assuming a bridge impedance of 350 Ω, we would have a nominal shunt resistance given by:

$$R_{SH} = \frac{350}{4 \cdot 0.00235} - \frac{350}{2}$$

$$= 37234 - 175$$

$$= 37059\ \Omega$$

Case (b): You have four bonded strain gages, you know the Gauge Factor K is 2.1, and you wish to set the calibration point at 1000 μstrain (i.e. this is the value for full scale that you enter into the Model 8500 system).

Using (3) above:

$$R_{SH} = \frac{350}{4 \cdot 0.0021} - \frac{350}{2}$$

$$= 41667 - 175$$

$$= 41492\ \Omega$$

Note that full scale sensitivity $K \cdot \varepsilon$ is 2.1 mV/V, and the recognition code is selected accordingly in the Section "Sensitivity Setting" below.

Calibration Resistor Type

The calibration of the system will depend on the quality of the calibration resistors you use, so they must be of the highest possible temperature stability.

NOTE *For the kind of accurate calibrations that Instron and other calibration laboratories would do, the value of calibration resistance calculated above is only used as a starting point. Errors can occur due to wiring resistance, gage bonding, etc. The exact shunt resistor value is modified after comparing the transducer output against an accurate standard.*

Choosing the Recognition Resistor - Theory

When a Model 8500 sensor powers up or whenever a sensor is plugged into the Model 8500, the Sensor Conditioner examines the recognition code resistance. It measures the resistance, and then closes the calibration relay and measures the resistance again. If it finds that the two resistance values are the same, as is true of all Instron standard transducers because the relay K_2 is not installed for these, it looks up a pre-stored table of values and knows how to set up correctly for that transducer. If, however, it finds that the first resistance is zero and the second is zero or some other value, it knows this is a "user" transducer and uses the value of the second resistance R_{CODE} to find out how to set up as described below (if it finds that the first value of resistance is very large, it assumes an open circuit and that no transducer is thus connected).

If the Model 8500 finds a user transducer is installed, it next looks to see if that code already has a transducer assigned previously by the user, and if so, restores these parameters. It is not necessary to enter these a second time unless you wish to change the parameters. If it is an unknown transducer, you will have to enter the units, identifier, and full scale value as described in the "Units Selection" Section in Chapter 4 of the Operating Instructions manual.

Significance of the Code Values

The value of the recognition code resistance determines which of each of the following four characteristics are to be used:

1) Excitation level	2 values (5V rms or 15V rms)
2) Sensitivity setting	4 values
3) Calibration type	2 values
4) Serial code	2 values

Excitation Level

The normal excitation is 5V rms at 5 kHz, for gauge resistances of 120 Ω and above. However, for certain transducers with gauge resistances equal to 350 Ω or above and low output, it is possible to select 15V rms excitation, which will improve the signal-to-noise ratio at the possible expense of temperature sensitivity.

Sensitivity Setting

The input amplifier on the sensor conditioner card has four possible gain settings, and the optimum setting is the most sensitive one which will still ensure that the output cannot saturate at full scale. The available ranges depend on which excitation level was chosen above. In addition, if an LVDT is used as an input on the Tower Rear Door instead of a strain gauge bridge, the preamplifier gain must be set to 1 instead of the normal 20 by changing the jumper resistors. For these three cases, the ranges of sensitivities are as shown in Table A-1

Table A-1. Sensitivity Settings

5V Excitation Strain Gauge Bridge 120 ohm or greater Preamp Gain = 20 (mV/V)	15V Excitation Strain Gauge Bridge 350 ohm or greater Preamp Gain = 20 (mV/V)	5V Excitation LVDT Preamp Gain = 1 (mV/V)
0.8 to 3.2	0.27 to 1.07	16 to 64
0.44 to 1.8	0.15 to 0.60	8.8 to 35
2.2 to 8.8	0.73 to 2.9	44 to 176
7.2 to 32	2.4 to 10.7	140 to 640

Calibration Type

The calibration type can be selected to be “manual” or “electrical”. If “manual” is selected, it means that no calibration resistor exists and the Model 8500 will not permit automatic calibration. If “electrical” is selected, then the calibration resistor does exist. The Model 8500 will then allow both automatic and manual calibration, but you must define the calibration point, either from the Front Panel or the GPIB.

Serial Code

The Serial Code is used to differentiate between like transducers, and can range from “A” through “F”. It allows two transducers with the same excitation level, sensitivity setting and calibration type to be distinguished in the Model 8500 memory storage area. If you have more than two such transducers, you can gain extra codes by going to the next lower sensitivity setting for the others, with possibly only a small penalty in the signal-to-noise ratio.

Table of Model 8500 Code Values

The values for the code recognition resistors are shown in Table A-1. Since two resistor positions are available on the printed circuit board, each of these code values may be made up accurately as the sum of two resistances.

Table A-2. Code Resistance Values

Code Index	Value for R_{CODE} (ohms)	Sensitivity (mV/ V) with preamp. gain		Calibration Type	Excitation Voltage	Serial Code
		X20	X1			
1	0	3.2	64	Manual	5	A
2	120	1.8	35	Manual	5	A
3	240	8.8	176	Manual	5	A
4	360	32	640	Manual	5	A
5	510	3.2	64	Electrical	5	A
6	680	1.8	35	Electrical	5	A
7	820	8.8	176	Electrical	5	A
8	1000	32	640	Electrical	5	A
9	1120	1.07	N/A	Manual	15	A
10	1240	0.6	N/A	Manual	15	A
11	1360	2.9	N/A	Manual	15	A
12	1510	10.7	N/A	Manual	15	A
13	1680	1.07	N/A	Electrical	15	A
14	1820	0.6	N/A	Electrical	15	A
15	2000	2.9	N/A	Electrical	15	A
16	2120	10.7	N/A	Electrical	15	A
17	2240	3.2	64	Manual	5	B
18	2360	1.8	35	Manual	5	B

Table A-2. Code Resistance Values (continued)

Code Index	Value for RCODE (ohms)	Sensitivity (mV/ V) with preamp. gain		Calibration Type	Excitation Voltage	Serial Code
		X20	X1			
19	2510	8.8	176	Manual	5	B
20	2680	32	640	Manual	5	B
21	2820	3.2	64	Electrical	5	B
22	3010	1.8	35	Electrical	5	B
23	3140	8.8	176	Electrical	5	B
24	3280	32	640	Electrical	5	B
25	3440	1.33	64	Manual	5	C
26	3630	0.73	35	Manual	5	C
27	3830	3.6	176	Manual	5	C
28	4020	11.6	640	Manual	5	C
29	4150	1.33	64	Electrical	5	C
30	4290	0.73	35	Electrical	5	C
31	4450	3.6	176	Electrical	5	C
32	4640	11.6	640	Electrical	5	C
33	4840	3.2	64	Manual	5	D
34	4990	1.8	35	Manual	5	D
35	5170	8.8	176	Manual	5	D
36	5350	35	640	Manual	5	D
37	5500	3.2	64	Electrical	5	D
38	5740	1.8	35	Electrical	5	D
39	6040	8.8	176	Electrical	5	D
40	6220	32	640	Electrical	5	D
41	6400	3.2	64	Manual	5	E
42	6600	1.8	35	Manual	5	E
43	6790	8.8	176	Manual	5	E

Table A-2. Code Resistance Values (continued)

Code Index	Value for RCODE (ohms)	Sensitivity (mV/ V) with preamp. gain		Calibration Type	Excitation Voltage	Serial Code
		X20	X1			
44	6980	32	640	Manual	5	E
45	7160	3.2	64	Electrical	5	E
46	7340	1.8	35	Electrical	5	E
47	7540	8.8	176	Electrical	5	E
48	7730	32	640	Electrical	5	E
49	8060	3.2	64	Manual	5	F
50	8280	1.8	35	Manual	5	F
51	8530	8.8	176	Manual	5	F
52	8810	32	640	Manual	5	F
53	9090	3.2	64	Electrical	5	F
54	9310	1.8	35	Electrical	5	F
55	9560	8.8	176	Electrical	5	F

Instron Calibration Service

Instron offers a standard calibration service which will provide the correct calibration and recognition resistors for your transducers, or for older Instron transducers. This service is provided at our Canton, Massachusetts facility at a reasonable cost, using our in-house standards, traceable to the U.S. National Bureau of Standards.

Appendix B

Use of Event Detectors

Outline

- Test Definition .... Page B-2
- Analyzing the Test Requirements .... Page B-3
- Setting Up The Test .... Page B-7
- Test Results .... Page B-11
- Test Modification .... Page B-15

This appendix details an example of a test in which Event Detectors are set to monitor the test for specific events and to take actions once those events are encountered.

Test Definition

This test is an example of how to set up the Event Detectors for certain test events, and the action the Event Detector will take when an Event occurs.

For this test, the specimen is to be subjected to fatigue via sinusoidal cycling at 4 Hz between 0.23 and 0.51 percent strain until the maximum cyclic load falls off to 90% of the largest cyclic load seen. When this condition is reached, the cycling is halted and the specimen pulled to break in load control at a 0.1 kN/sec ramp rate. A plot of load versus strain is required from the start of the monotonic pull to the break point.

Analyzing the Test Requirements

Identification of Transition Points

The first step in using event detectors to help perform this test is to identify the major transitions, i.e. events, that divide the test into distinct regions. This test contains only two important transitions, that from cyclic loading to monotonic loading, and that from monotonic loading to the end of test. The first transition is specified as a 90% underpeak condition. The second is specified simply as specimen break. Thus, two single-shot Event Detectors on the Load channel are required, one set as an Underpeak Detector, the other as a Break Detector. The Break Detector, however, must not be turned on until after the Underpeak Detector has tripped. Otherwise the Break Detector might trip during cycling.

Transition 1 Event Detector

A number of things must happen at the transition from the cyclic loading section to the monotonic loading section. The Waveform Generator must be stopped and the Ramp Generator started. In addition, a mode transfer to Load Control must be performed, since the cycling is performed in Strain Control and the monotonic loading is in Load Control. Finally, the Data Logging must be started to capture the load and strain data during the pull to break.

Although many of these things can be programmed to happen in realtime using the block transfer feature, we have chosen to use the programmed buffer feature instead, both to demonstrate this feature and to avoid introducing additional advanced features at this stage in the example. In this case, it is also good programming practice. Because the transition between blocks is not really time critical for this application, it is simpler and more flexible to implement using programmed buffers than block programming

The approach, then, will be to use the realtime action for the Underpeak Detector simply to hold the Waveform Generator and the Data Logging action to enable data logging. A programmed buffer attached to this Event Detector will do the additional work of setting the Increment Detectors to the ON state, switching control modes to Load Control, and starting the ramp.

Data Logging

Taking data during the monotonic loading section offers an opportunity to use repeating Event Detectors to define when logging should occur. During a pull to break in Load Control, the test accelerates tremendously after the specimen starts to yield. If data is taken based on intervals in time, too few points will be taken during the elastic portion of the curve and too many points will be taken during the plastic portion. Instead, the logging should be based on intervals of load during the elastic portion and strain during the plastic portion. To do this, two repeating Event Detectors can be set up, one on the Load channel, and one on the Strain channel, with each set to the type INCREMENT and with the realtime action set to DATA LOG STROBE.

Transition 2 Event Detector

The final transition from monotonic loading to end of test requires stopping the Ramp Generator and Data Logging at specimen break. It also requires going to Position Control for safety because the system will be running open loop in Load Control after the specimen has broken. All these actions can be accomplished by selecting the realtime action as STOP and the Data Logging action as DISABLE for the Break Detector.

Final Choices

Overall, the test requires the use of four Event Detectors, three on the Load channel and one on the Strain channel. It requires one set of cyclic parameters for the Strain Waveform Generator, and one set of monotonic parameters for the Load Ramp Generator.

Nearly all the setup for this test can be performed in advance of running the test, including the Strain waveform parameters, the Load ramp parameters, the Event Detector settings, and the program buffer for the Underpeak Detector. The Event Detectors used for incremental logging and break are set to the PREPARED state.

The Model 8500 will perform all the necessary runtime actions without intervention. The only exception is the value to which the Underpeak Event Detector threshold level must be set. This value must be calculated by monitoring the ultimate cyclic load maximum at the beginning of the test and calculating 90% of this value. This can be done using the Ultimate Peak Monitor, either through the computer or manually from the Front Panel.

Summary

Let's review the entire test sequence now as it occurs in realtime. First, the Strain cyclic waveform is started and the maximum cyclic load monitored until it levels off or begins to drop. The Load Underpeak Event Detector threshold is then set to 90% of the largest cyclic load measured and the Event Detector is turned on.

The test proceeds until the Underpeak Detector trips. At this point, the realtime action occurs immediately, putting the Waveform Generator into the HOLD state, and the Data Logger into the STARTED state. The program buffer then executes. It contains commands to set the PREPARED Event Detectors to the ON state, change modes to Load Control, and start the Load ramp.

The test proceeds, logging data on increment now, until the specimen breaks. At this time, the Break Detector trips and its actions cause the system to go to the STOP state, i.e. Position Control holding the current position, and the Data Logger to go to the IDLE state.

Setting Up The Test

A list of all the commands necessary to set up and run this test is given with explanations of each command. A copy of the Model 8500 command set (from the Model 8500 GPIB Interface manual) should be on hand when studying this example. The commands are grouped according to functionality to facilitate understanding.

8500 COMMAND	**DESCRIPTION**
Set Up Waveform Parameter	
C201,3,0	Set Strain waveshape to sine.
C202,3,4.0	Set Strain frequency to 4 Hz.
C203,3,0.014	Set Strain amplitude to 1.4 % of full scale, assuming an extensometer full scale of 10% strain.
C3,3,0.037	Set SET LEVEL in Strain Control to 3.7 % of full scale.
Set Up Ramp Parameters	
C2,2,0	Set Load ramp type to SINGLE RAMP
C4,2,0.5	Set Load ramp amplitude to 50 %
C6,2,0.001	Set Load ramp rate to .1% / sec, assuming a 100 kN load cell.
Set Up Underpeak Detector	
C125,2,1,0	Set state to RESET, using first Load Event Detector.
C127,2,1,3	Set type to UNDERPEAK

C128,2,1,0	Set sign to NEGATIVE so that maximum underpeak is selected.
C129,2,1,3	Set realtime action to HOLD.
C130,2,1,2	Set Data Logging action to START.
C322,1,3,2,1,"C301;C300,2;C1,1"	Attach program buffer 1 to load Event Detector 1. The program buffer commands will perform the following actions: C301- Universal ARM. C300,2 - Change to Load Control C1,1 - Ramp state to START.

Set Up Break Detector

C125,2,2,0	Set state to RESET, use second load Event Detector.
C127,2,2,5	Set type to BREAK.
C135,2,2,4	Set amplitude drop to 6.25%.
C136,2,2,50	Set break time window to 50 msec.
C129,2,2,2	Set realtime action to STOP.
C130,2,2,1	Set Data Logging action to DISABLE.
C125,2,2,1	Set state to PREPARED

Set Up Increment Detectors

C125,2,3,0; C125,3,1,0	Set states to RESET, use third Load Event Detector, first strain E.D.

C127,2,3,4; C127,3,1,4	Set type to INCREMENT
C126,2,3,0.001; C126,3,1,0.001	Set both increments to 0.1% full scale.
C129,2,3,5; C129,3,1,5	Set realtime action to DATA LOG STROBE
C130,2,3,0; C130,3,1,0	Set Data Logging action to NONE
C125,2,3,1; c125,3,1,1	Set state to PREPARED

Set Up Data Logging

C316,0; C316,1	Clear Logger, put state to IDLE.
C317,0,0,1	Set mode to NORMAL, time increment to NONE, and buffer count to 1.
C319,500,0	Set buffer size to 500 points.
C318,0,1,2; C318,1,1,3	Set logging vector to load and strain.
C316,2	Set state to STOPPED, ready for real time transition to STARTED.

Start Test

C216,1	Set Constant Amplitude control state to ON.
C200,1	Set cyclic state to START.

At this point, the cyclic load maximum is monitored. When running this example, we observed the maximum load to be 6.1 kN. The threshold value for the Underpeak Detector was determined to be 0.9 *6.1= 5.5 kN. The following commands finish the example.

C126,2,1,0.055	Set threshold value on Underpeak Detector to .055 % of full scale.
C125,2,1,2	Set ED state to ON.

Test Results

At the end of the test, the Data Logging buffer contains the Load- Strain Curve for the pull to break. Figure B-1 shows a plot of the data which looks like a classic tensile test, although the data does not start at the zero load-zero strain point. This is because the start of the ramp is determined by the end of the previous block

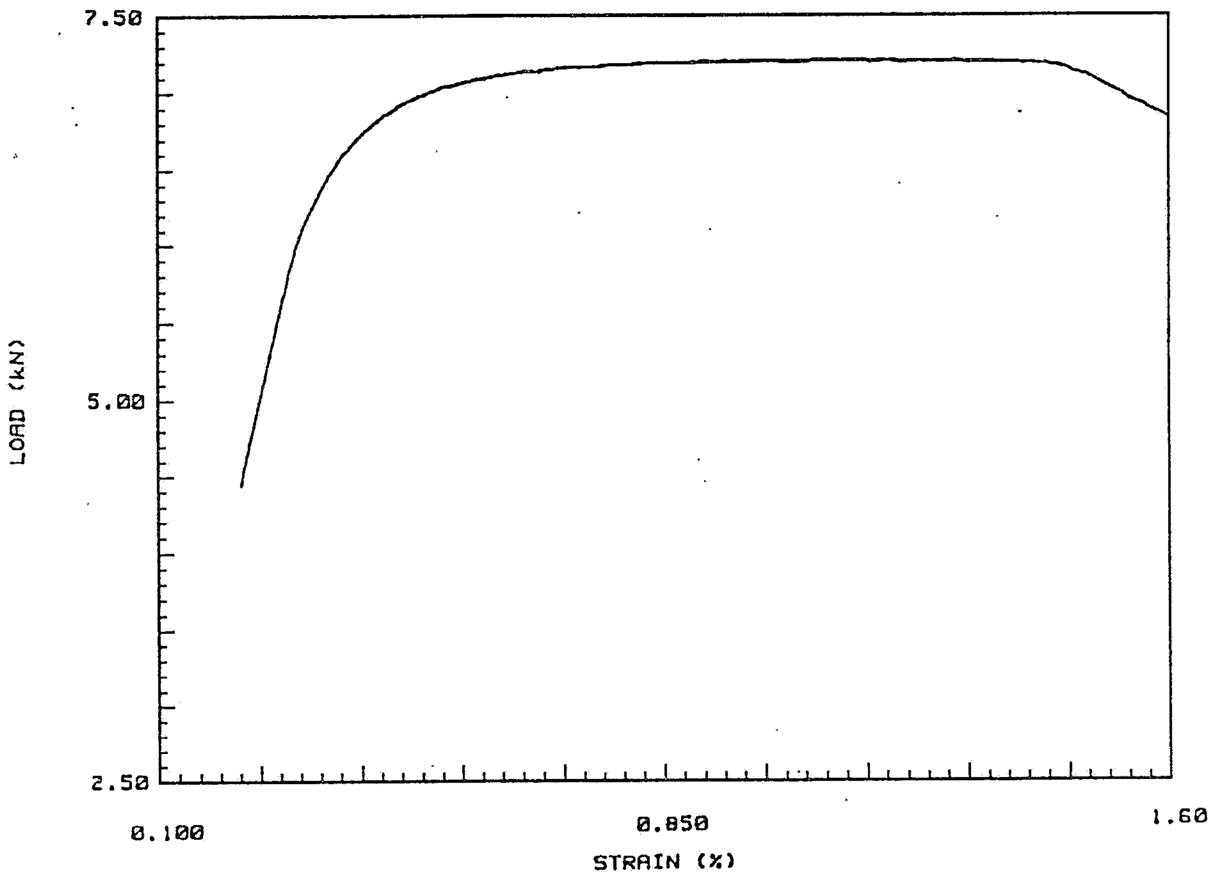


Figure B-1. Test Example Load-Strain Curve

The Underpeak criterion was set to 5.5 kN, but the apparent transition point between the cyclic block and the ramp block, as judged by the first point of the curve, is around 4.4 kN. The difference is due to the phase lag between command and feedback during cyclic testing. The feedback slightly lags the command, so that when the underpeak is detected at the peak of the feedback and the HOLD action is taken, the command is already part way down to the mean level. Thus, the Waveform Generator holds this level. The system catches up, that is, the feedback becomes equal to the command, during the few milliseconds delay between the Event Detector trip and the processing of the mode change command in the programmed buffer.

The effect of logging on increment is dramatically demonstrated in Figures B-2 and B-3. Figure B-2 is a plot of Strain versus Time. The shape of the curve shows the tre-

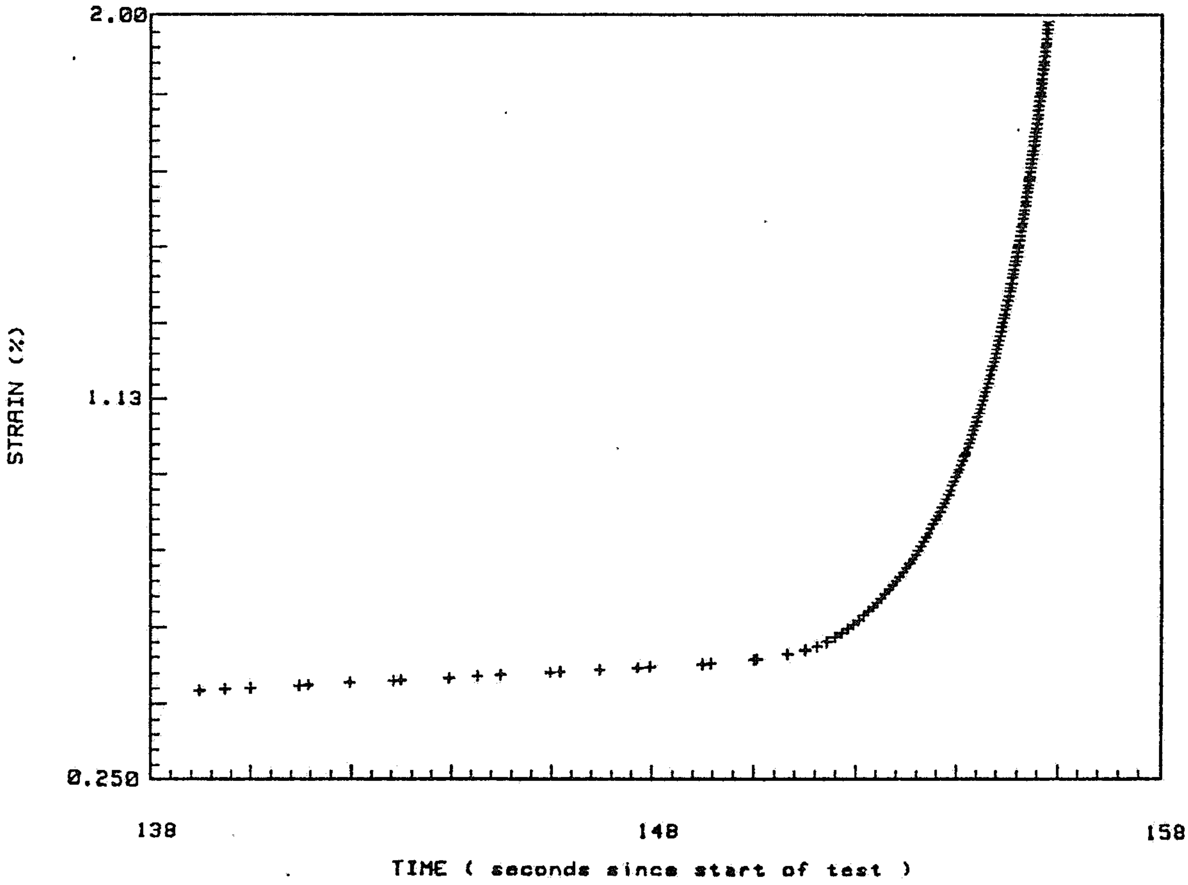


Figure B-2. Strain Rate Acceleration

mendous acceleration in the strain rate that occurs when the specimen yields. During the elastic region, strain is proportional to load. Since load is increasing linearly with time (recall that the system is running a load control ramp), strain does also. As yield occurs, it takes increasingly more strain to achieve an increment of load. The system continues to increase load linearly in time resulting in an accelerating rate of strain. The increment in time between points shows that the logging rate goes from between 1 and 2 points per second at the 140 second mark to over 50 points per second at the 155 seconds mark. The logging rate has increased some 50 times.

Figure B-3 shows an expanded view of the "knee" of the Load-Strain curve in Figure B-1, where specimen yielding occurs.

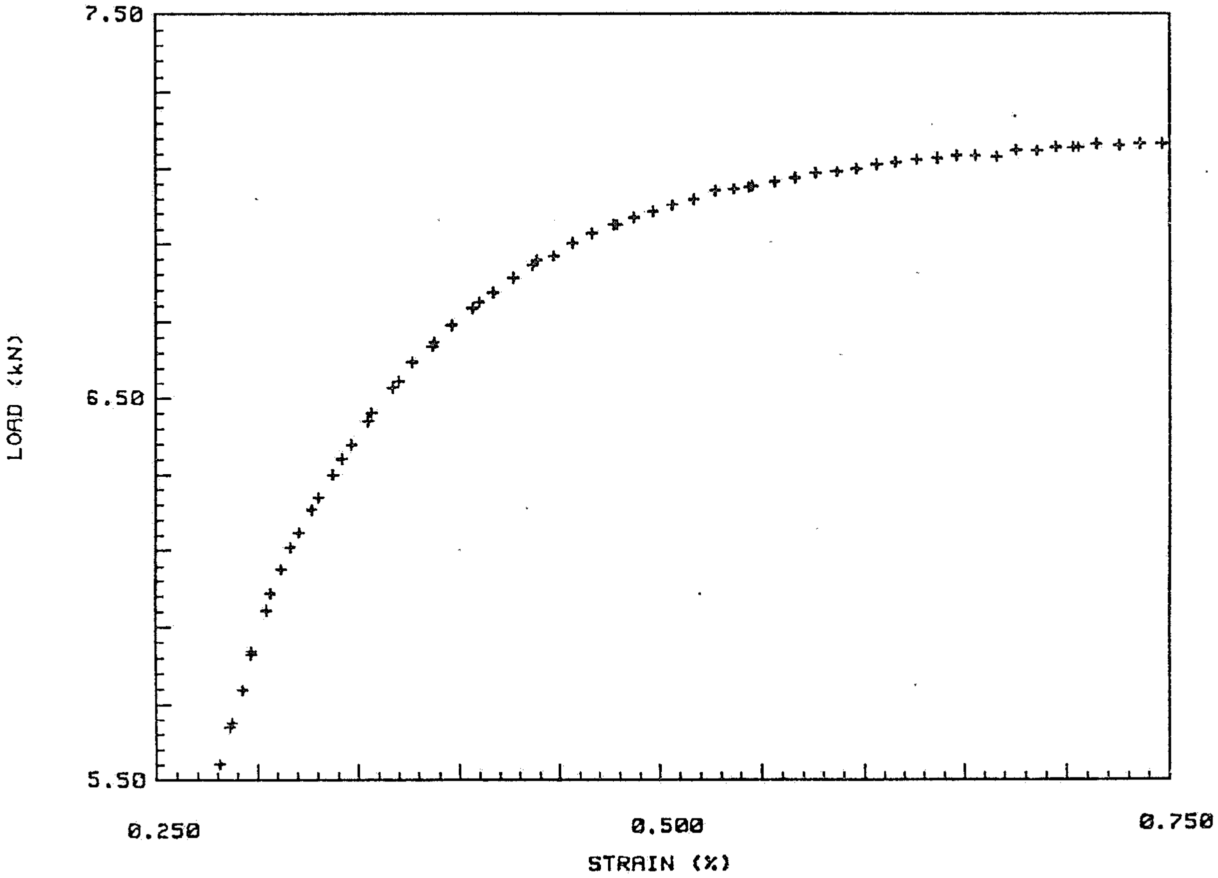


Figure B-3. Expanded View of Load-Strain Curve

Note how the 50-fold increase in the data logging rate results in a very even distribution of points along both the elastic and plastic regions of the test, at the lower left and upper right corners respectively.

It is also important to note how little runtime interaction was required to run this test. In the past, this type of test has been run using computer intensive supervision of the test to perform such functions as watching for underpeaks. This required large amounts of data to be logged by the system, transferred to the computer, and analyzed. During the pull to break, again, much more data than necessary would have been taken in order to ensure that no data was lost, with the majority of the data being discarded after analysis at the computer. Such supervision consumed virtually all of the available computing resources of a PC, a serious waste if the test lasted for several days.

Running this test, as demonstrated, on the Model 8500 would only require sending the setup commands and performing relatively infrequent checks of the maximum load near the beginning of the test until the underpeak level was established. After this point, the computer need not supervise the Model 8500 any further until the end of the test, at which time the buffer which contains only the relevant data would be read. A single PC could easily supervise 10 or more systems running this type of test simultaneously.

Test Modification

The above example can be modified to reinforce the benefit of incremental logging. It is often quite likely that a user running a test of this sort would like to have hysteresis plots of the last 10 cycles of the test. This can be accomplished by using the Ring Mode Data Logging feature of the Model 8500 in conjunction with Incremental Logging.

First, the Logging mode is changed to use RING mode logging instead of NORMAL mode. Second, the Increment Detectors are put directly into the ON state at setup, instead of the PREPARED state. Third, the Data Logger is put into the STARTED state at setup instead of the STOPPED state. To be complete, the universal ARM command can be removed from the Underpeak program buffer and Data Logging action set to NO ACTION, although these changes are not necessary. As an aid to demonstration, TIME is also included in the logging vector.

When this test is run with these changes, the logging buffer will start filling immediately with samples because the cycling load and strain signals will cause the Incremental Detectors to trip. When the buffer fills, the data wraps around and begins overwriting the oldest data in the buffer. The number of points per cycle is determined by the ratio of the cyclic amplitude to the increment threshold. For this example, the strain amplitude is 0.28% peak-to-peak, while the increment is 0.01%. Thus, each cycle will cause 56 increment trips in strain. Similarly, the load amplitude was observed to be 4.8 kN. The Load Threshold Increment is 0.1 kN so there are 96 load trip increments per cycle. The maximum number of points taken per cycle is the sum of these two numbers. (The actual number taken will be less by the number of times a load increment and strain increment trip on the same sample period.) The maximum number of points per cycle then is 152 and this value is independent of the frequency at which the test is run.

Setting the Data Logging buffer size to 1520 points would mean that any time during the cycling that logging were stopped, the buffer would contain at least the last 10 cycles of information. Similar analysis can be used to estimate the maximum number of points required to capture the entire tensile curve. The resulting estimate can be added to the maximum points determined to capture 10 cycles. In this case, 250 points is a generous estimate, so the total buffer size should be set to 1770 points.

Running the test with this additional change means that at specimen break, the logging buffer contains the last ten cycles worth of data and the load strain curve for pull to break. Again, there is a great variation in time scales between the various regions of the test. This can be seen clearly by plotting Load versus Time as shown in Figure B-4.

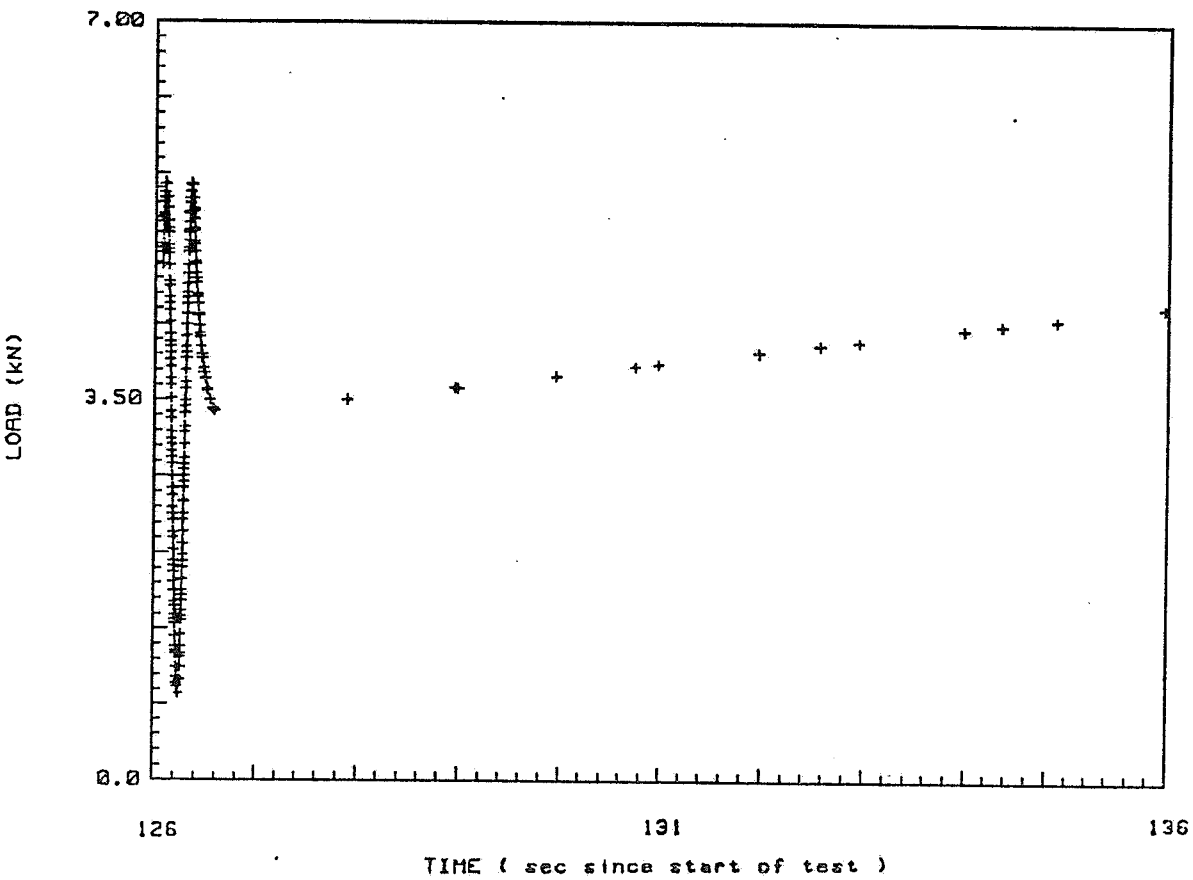


Figure B-4. Plot Showing Capture of Last Cycle

Here, the last cycle is plotted along with the beginning of the load ramp. The disparity in data rates between the cycling and the monotonic loading regions is clear.

Figure B-5 shows a hysteresis curve for the last cycle obtained by plotting the load versus strain data.

Incremental Logging provides three major benefits. First, no meaningless data is taken. This eliminates the wasted time and processing required to transfer large amounts of data to the computer and analyze it. Second, the taking of data is decoupled from time, being scaled instead to the sample and test characteristics. This means the same logging setup is applicable to a wide range of testing conditions. Finally, the increment can be used to predict the maximum buffer size required so that no meaningful data is lost.

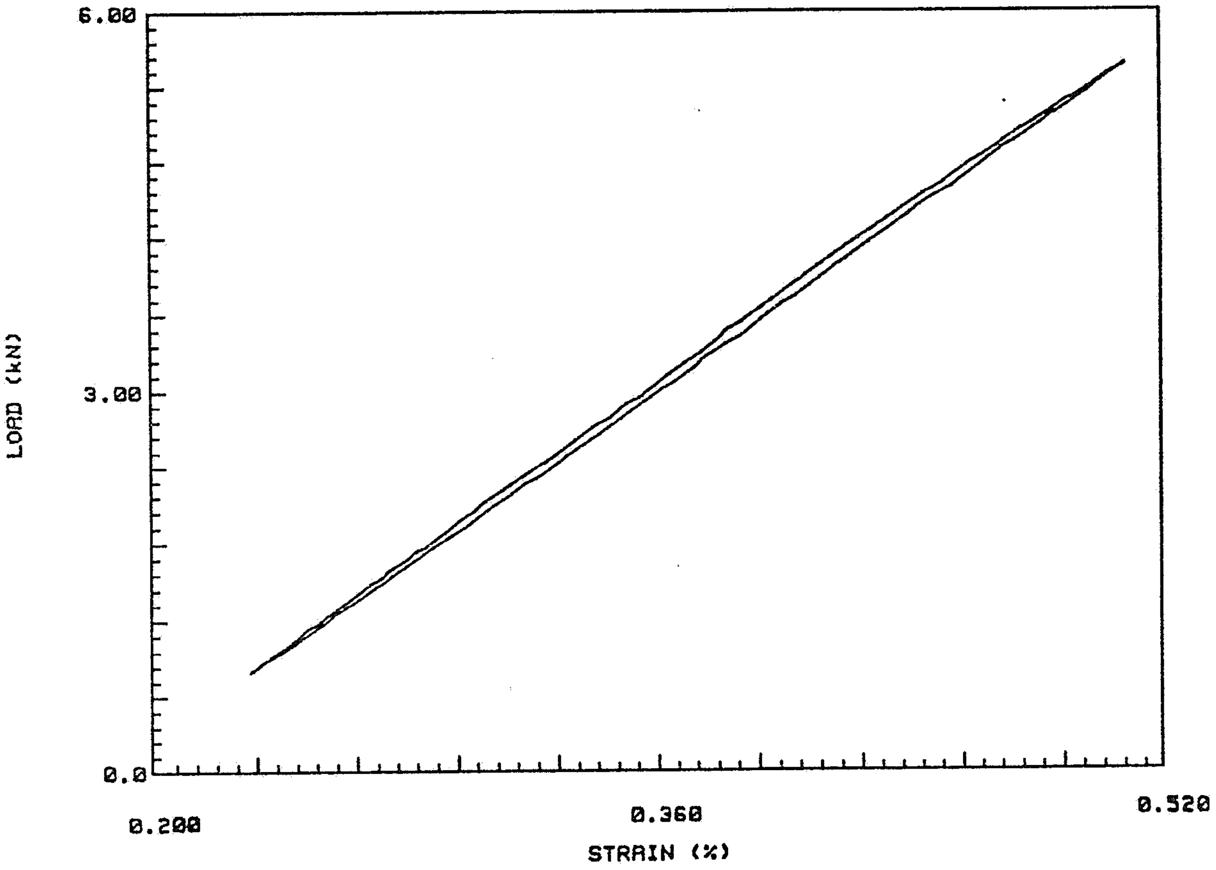


Figure B-5. Hysteresis Plot of Last Cycle

Appendix C
Digital Data Resolution

Outline

- Introduction . . . . Page C-2
- Data Resolution Issues For Digital ControlPage C-4
- Conclusion . . . . Page C-12

This appendix is an excerpt from an Instron Technical Note produced by the Model 8500 design team. It is reprinted here to describe the advantages of digital control of servohydraulic materials testing systems and to give further insight into the design concepts behind the Model 8500.

Introduction

Previous servohydraulic control systems have used analog-to-digital converters external to the control electronics to obtain digital data for use by a computer. The computer was typically burdened with the task of converting the raw A/D values to engineering values. This conversion involves at least one linear calibration of an $mx+b$ form, and two for some systems. Furthermore, 12-bit or 14-bit A/D converters were used, which provide marginal resolution for the wide range of data requirements encountered in materials testing. Zero Suppression and Ranging of the analog signal, either within the controller or just before the converter provided the necessary increase in converter resolution. However, the computer was then further burdened with decisions of what range to choose to maximize resolution without over-ranging the converter, and with performing yet another linear correction to normalize the suppressed and ranged data back to true engineering values.

In the Model 8500 Controller, *the digital data is used inside the loop*, and hence requires much greater resolution. Also, corrections for ranging and zero suppression must be performed within the controller before the data is passed to the control loop. To meet these needs, each Model 8500 Sensor Conditioner contains a dedicated 16-bit A/D Converter with zero suppression and ranging circuitry to provide high resolution, combined with a 68000 microprocessor to add local intelligence to the conversion process. For each data sample from the A/D converter (converted at a 5 kHz rate), the processor performs all the calculations necessary to calibrate and normalize the raw suppressed and ranged A/D value to a fractional value of full scale (similar to percent full scale). The processor can also perform automatic range selection for the next conversion based on the current signal level. The result is data which effectively has 19-bit resolution, is fully normalized, yet can still cover the full physical range of the transducer at all times without overranging. This data is used by the control loop and is also available to the computer. The computer overhead to convert the values to engineering values is reduced to a single multiplication by a Full Scale factor.

Data Resolution Issues For Digital Control

Finding the Maximum Affordable A/D Converter Resolution

The design of the Model 8500 required increasing the resolution of the digital data to the point where the system cannot see the effect of the digitization process. The first step in this process naturally is to obtain the maximum resolution at the converter consistent with system "costs" (in system resources, not just monetary). Data conversion time and converter cost were limiting factors in choosing the converter for the Model 8500 system. The maximum resolution "affordable" within these limits was 16-bit, with 14-bit guaranteed monotonicity and linearity.

Finding a Limit on Usable Resolution

The major factor limiting the benefit seen from increased resolution is the noise on the analog signal being converted. The resolution is too coarse if the step size is larger than the analog noise. In this case, the converter can "stick" at a level, and information about where the analog signal is between successive steps is lost. When the step size becomes smaller than the analog noise, the converter will always be bouncing between two or more levels. The mean of the digital data stream then provides information about where the mean of the analog signal is between resolution steps. How closely the mean of the digital samples tracks the mean of the analog signal then becomes the crucial question for determining the need for further resolution.

Another way of looking at this is to consider the effective noise introduced by the digitization process, i.e. the quantization noise. Quantization noise adds a random noise component to a signal with an rms value of $\frac{D}{3.5}$, where D is the step size of the converter. Thus, when $\frac{D}{3.5}$ becomes less than the analog noise rms value, further decreases in D become increasingly less important. Where to draw the line on increasing resolution is a complex question involving the overall system dynamics and the data sampling rate. Consideration must also be given to the "cost" of increasing resolution.

Comparing Converter Resolution to Usable Resolution

In the Model 8500 system, the 16-bit converter applied to the full scale ±10.9 volts signal yields a step size, D, of 333 µV. Thus, the quantization noise added by the converter is 95 µV rms. These values must be compared to the best case noise levels of the analog signals, measured to be 240 µV pp, or 40 µV rms in the Load channel, and 132 µV pp or 22 µV rms in the Position channel, both at 100 Hz bandwidth with the hydraulic pressure off.

All the above numbers are best case figures, with each susceptible to various types of degradation. For example, the converter can have non-linearities, causing missing codes or sticky bits, which make the resolution steps appear larger. Similarly, there are many sources of noise, which can increase the analog noise levels, such as the hydraulic system, temperature variations, RFI, frame vibrations, or simply using the full 1000 Hz bandwidth of the signal. Note that the signal amplitudes being discussed are extremely small.

These best case figures are useful for getting a feel for what resolution is required so that the overall system shows no degradation from the digitization process. Particularly, since the step size is larger than the peak-to-peak noise, it is clear that better than 16-bit resolution is required if the controller is to accurately take advantage of all the information present in the analog signal.

Increasing The Effective Resolution Of The Converter

How Analog Ranging Increases Effective Resolution

To increase effective resolution of the converter, the sensor conditioner has plus and minus full scale zero suppression and ranging of the analog signal before the converter. The maximum range of times 64 gives an effective resolution of 22 bits over a signal range of 1/64 of full scale from the zero suppression point. On the times 64 setting, D is 5 µV and the quantization noise is 1.5 µV rms. The analog noise is 15 or more times the digital noise, and increasing resolution would be meaningless.

Figures C-1 through C-3 show this ranging effect for a typical case. Each presents a snapshot of Load digital data taken over several seconds using the x1, x8, and x32 ranges respectively, and the full 1000 Hz signal bandwidth. The rms value of the noise was calculated in each and an estimate of the peak-to-peak noise appears at the right edge of the graph. The first point of interest is that the noise levels are higher than the best case ones cited above, primarily due to the increased bandwidth.

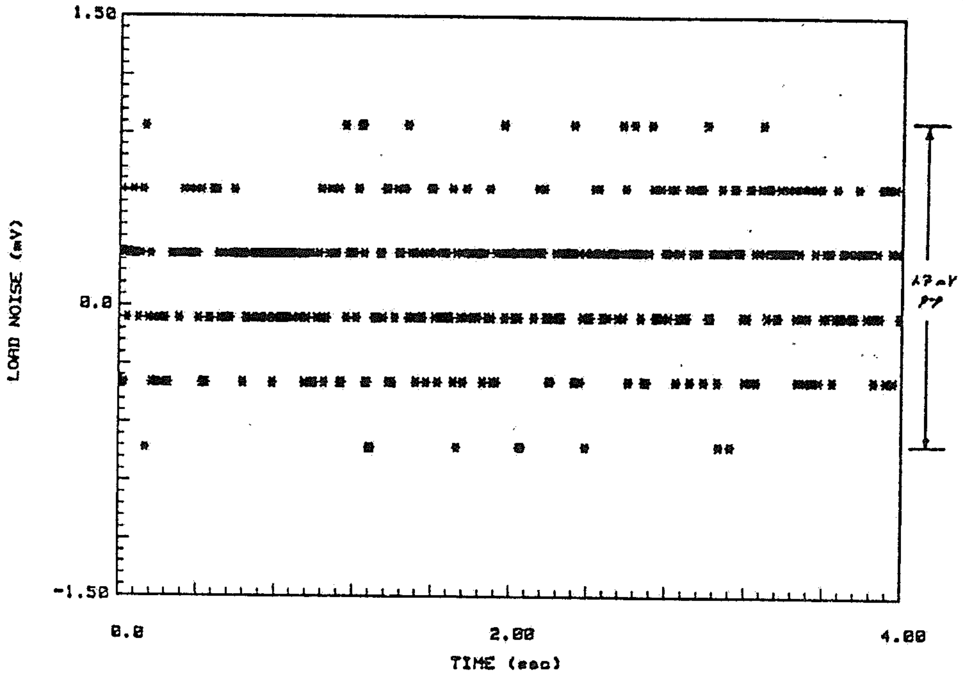


Figure C-1. Digital Load Data at Times 1 Range

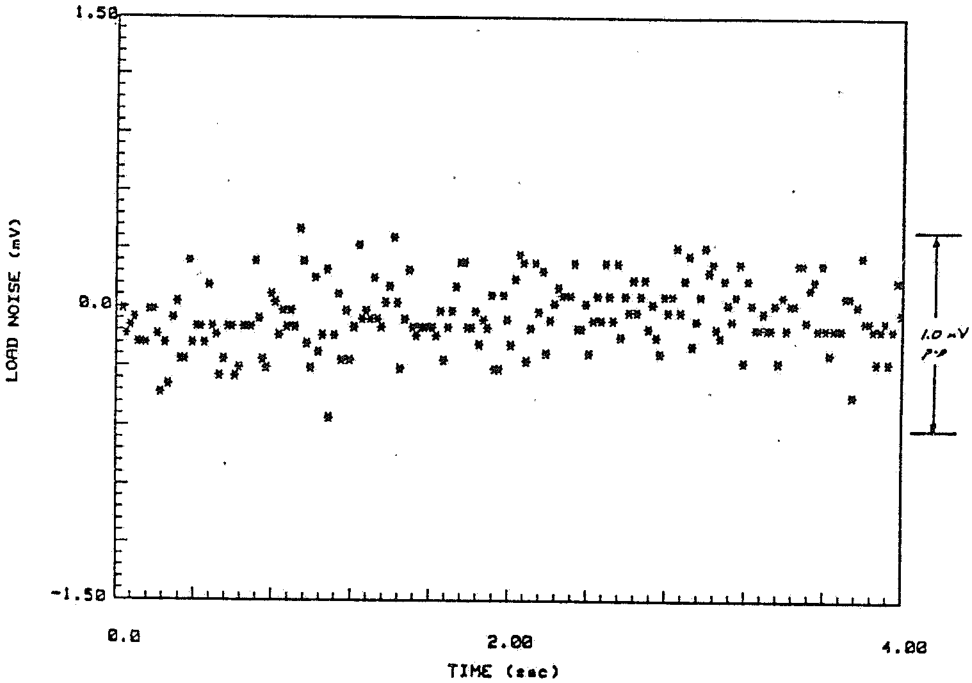


Figure C-2. Digital Load Data at Times 8 Range

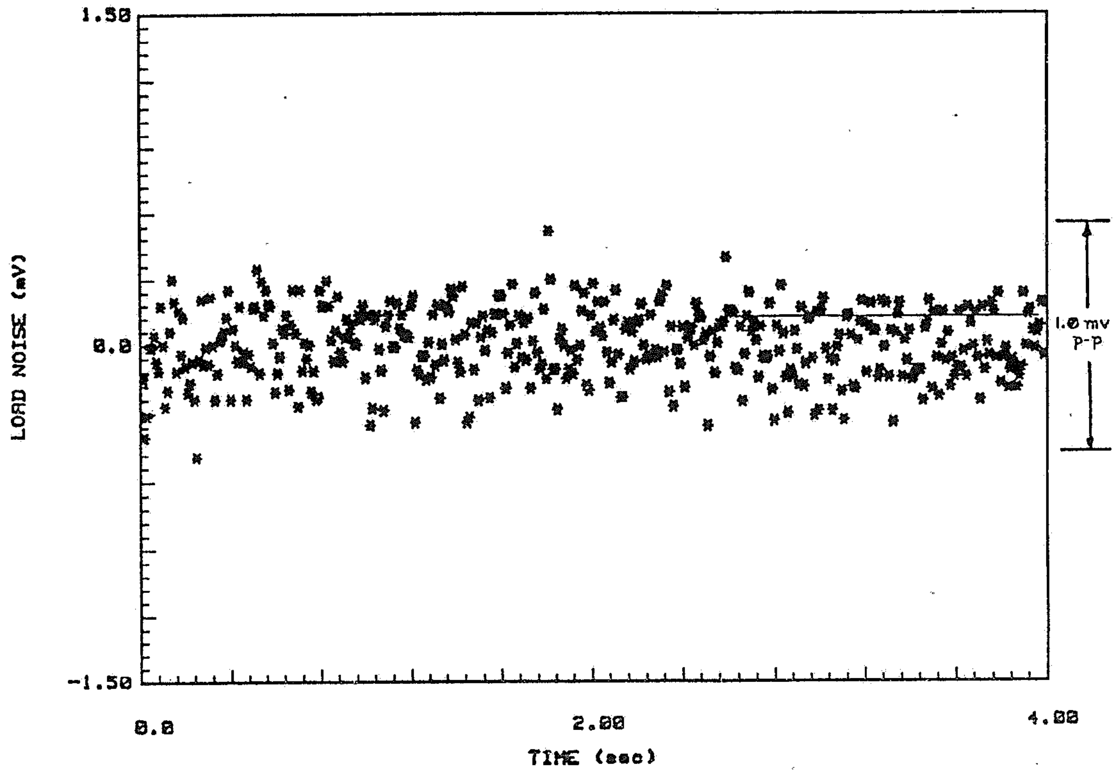


Figure C-3. Digital Load Data at Times 32 Range

Still, the minimum noise of 160 µV rms (1.0 mV pp) is quite low, being several times less than the old Instron Model 2150 Analog System specification, for example. Second, the quantization errors on these ranges are 95, 12, and 3 µV rms, giving delta noise changes of 83 and 9 µV, whereas the measured values of 320, 160, and 160 µV rms show deltas of 160 and 0. Ideally, the differences between the various ranges would correspond directly to the change in quantization error. The discrepancies result in part from the imperfections in the quantization steps of the A/D. It is important to note that for the typical case, the improvement between the x8 range and the x32 range is negligible.

Disadvantages Of Fixed Analog Ranging

While proper ranging makes the quantization noise insignificant, fixed manual ranging has serious disadvantages. Even though the Model 8500 data is corrected for zero suppression and range, which reduces the post-test overhead at the computer, manual ranging still requires the operator to select the appropriate range before the test, opening the possibility of lost data due to over-ranging. Alternatively, since manual range changes on the Model 8500 can be made at any time by the operator during a test without disturbing the data (a feature not available on previous analog controllers), the operator or computer could monitor the test in real time and change the range when necessary. Still, this is a slow and time-consuming task.

Realtime Automatic Ranging

Advantages of Automatic Ranging

To overcome these disadvantages, *realtime automatic ranging has been implemented in the Model 8500.* With auto ranging, the operator interaction with the ranging of the system is minimal. The range never need be selected explicitly on any channel, just left in Auto Range at all times. The digital data will have full 19-bit resolution within ±10% of the transducer full scale from the zero suppression point. The operator only needs to set the zero suppression point somewhere near the region of the data that requires the most resolution. If the signal moves farther than ±10% from this point, no data is lost; the data just gradually sheds resolution to the 16-bit level afforded by the converter at the x1 range. Over-ranging will never occur unless the test exceeds the physical limits of the transducer, or the data moves farther than ±109% of full scale from the zero suppression point.

How Auto-Ranging Works

The ultimate goal of Auto-Ranging is to obtain the maximum possible resolution for each data sample without ever losing a single data point by being on too sensitive a range and over-ranging the converter. With Auto-Ranging, the processor examines each A/D reading, in real-time at the 5 kHz sampling rate, and sets the range for the next reading. If the current reading is above the upper threshold, the processor selects a less sensitive range for the next sample, unless the hardware is already on the least sensitive x1 range. Similarly, if the sample is below the lower threshold, the processor selects a more sensitive range, unless the range is at the most sensitive allowed range. To avoid ever losing data, the most sensitive range must be chosen so that the maximum slew rate of the signal cannot cause the signal to move from just under the upper threshold to the over-range condition in less than one sample period, which is 200 µsec. This corresponds to the x8 range for a Model 8500 Servohydraulic system and the x16 range on a Model 8560 Electric Actuator system (due to the decreased signal bandwidth).

On the x8 range, the added quantization noise value is 12 µV rms, roughly half the best case Position rms noise value, and a third of the Load value. On this range, the peak-to-peak analog noise spans at least three converter steps on the Position channel, and nearly six on the Load channel. Empirical means must be used at this point to determine if the system would benefit from increased resolution.

Demonstrating the Effectiveness of Auto-Ranging

The most demanding test we could think of for resolution is a Position controlled test on a very stiff specimen having high cross-channel gain. Any resolution steps in the controlling Position channel will show up many times larger in the Load channel. A group of such tests was run, and, in summary, it was found that when running very low amplitude triangle and sine waves (on the order of 1 micron), and slow ramps (on the order of 1 micron/minute), no steps could be detected in the Load channel output. The conclusion is, that on the x8 range, the feedback resolution is so fine that it has no measurable impact on the system performance. The digital data stream captures all the useful information present in the analog signal and there is no reason to use a finer maximum range for the Auto-Range algorithm. The x8 range effectively adds three bits of resolution to the signal, and the resultant 19-bit resolution yields data which is essentially free of quantization effects.

Conclusion

The advent of digital control has placed new, more stringent demands on the digitization of analog transducer signals. To meet these demands, the Model 8500 Sensor Conditioner uses a high-resolution A/D Converter, coupled with zero suppression and ranging circuitry, and a 68000 microprocessor dedicated to each analog signal to be converted. The result is fully calibrated and normalized data with 19-bit effective resolution around a point of interest (zero suppression point) and full 100% of transducer full scale range from this point. This high quality data is available to a computer. The overhead in converting such data to true engineering values is reduced to one multiplication by a full scale factor.

Appendix D
Glossary

Outline

This Glossary is a summary of many of the properties, tests, and terms you may find in the Model 8500 set of Instruction Manuals. It also contains the names of devices and functions you may encounter in operating the Model 8500 Materials Testing System.

Engineering materials are commonly defined and specified by their properties. Of all the properties a material may possess, mechanical properties are often the most important because virtually all fabrication processes and most service conditions involve some type of mechanical loading. As this glossary shows, there are literally hundreds of different mechanical properties and terms. Behind each property there generally is a test that defines the property and tells how to measure it.

Adherence

The extent to which a coating bonds to a substrate.

Adherence Index

Measure of the adherence of porcelain enamel and ceramic coatings to sheet metal. (ASTM C-313)

Alpha Rockwell Hardness

Index of the resistance of a plastic to surface penetration by a specified indentor under specified load applied with a Rockwell hardness tester. Higher values indicate higher indentation hardness. (ASTM D-785)

Bend Test

Method for measuring ductility of certain materials. There are no standardized terms for reporting bend test results for broad classes of materials; rather, terms associated with bend tests apply to specific forms or types of materials. For example, materials specifications sometimes require that a specimen be bent to a specified inside diameter (ASTM A-360, steel products). A bend test for ductility of welds is given in ASTM E-190. Results of tests of fiberboard are reported by a description of the failure or photographs (ASTM D-1037).

Bending Strength

Alternate term for flexural strength. It is most commonly used to describe flexure properties of cast iron and wood products.

Bond Strength

Stress (tensile load divided by area of bond) required to rupture a bond formed by an adhesive between two metal blocks. (ASTM D-952).

Break Detector

Digital function in the Model 8500 which detects the fracture of the test specimen. Can be set up to perform a user-selected action when specimen break is sensed.

Breaking Load

Load which causes fracture in a tension, compression, flexure or torsion test. In tension tests of textiles and yarns, breaking load also is called breaking strength. In tensile tests of thin sheet materials or materials in form of small diameter wire it is difficult to distinguish between breaking load and the maximum load developed, so the latter is considered the breaking load.

Breaking Strength

Tensile load or force required to rupture textiles (e.g., fibers, yarn) or leather. It is analogous to breaking load in a tension test. Ordinarily, breaking strength is reported as lb. or lb/in of width for sheet specimens.

Bulk Modulus of Elasticity

Ratio of stress to change in volume of a material subjected to axial loading. Related to Modulus of Elasticity (E) and Poisson's Ratio (r) by the following equation:

$$K = \frac{Er}{3(1-2r)}$$

Cleavage Strength

Tensile load (lb/in of width) required to cause separation of a 1-in. long metal-to-metal adhesive bond under the conditions set in ASTM D-1062.

Climbing Drum Peel Test

Method for determining peel resistance of adhesive bond between a relatively flexible and a rigid material. (ASTM D-1781).

Coefficient of Elasticity

An alternate term for modulus of elasticity.

Cohesive Strength

Theoretical stress that causes fracture in tension test if material exhibits no plastic deformation.

Complex Modulus

Measure of dynamic mechanical properties of a material, taking into account energy dissipated as heat during deformation and recovery. It is equal to the sum of static modulus of a material and its loss modulus. In the case of shear loading, it is called dynamic modulus.

Compressibility

Extent to which a material is compressed in test for compressibility and recovery of gasket materials (ASTM F-36). It is usually reported with recovery.

Compressibility and Recovery Test

Method for measuring behavior of gasket materials under short time compressive loading at room temperature. ASTM F-36 outlines a standard procedure. This test is not designed to indicate long term (creep) behavior and should not be confused with the plastometer test.

Compression-Deflection Test

Nondestructive method for determining relationship between compressive load and deflection under load for vulcanized rubber. (ASTM D-575).

Compression Fatigue

Ability of rubber to sustain repeated fluctuating compressive loads (ASTM D-623).

Compression Set

The extent to which rubber is permanently deformed by a prolonged compressive load (ASTM D-395). Should not be confused with low temperature compression set.

Compression Test

Method for determining behavior of materials under crushing loads. Specimen is compressed, and deformation at various loads is recorded. Compressive stress and strain are calculated and plotted as a stress-strain diagram which is used to determine elastic limit, proportional limit, yield point, yield strength and (for some materials) compressive strength. Standard compression tests are given in ASTM C-773 (high strength ceramics), ASTM E-9 (metals), ASTM E-209 (metals at elevated temperatures) and ASTM D-695 (plastics).

Compressive Deformation

Extent to which a material deforms under a crushing load.

Compressive Strength

Maximum stress a material can sustain under crush loading. The compressive strength of a material that fails by shattering fracture can be defined within fairly narrow limits as an independent property. However, the compressive strength of materials that do not shatter in compression must be defined as the amount of stress required to distort the material an arbitrary amount. Compressive strength is calculated by dividing the maximum load by the original cross-sectional area of a specimen in a compression test.

Compressive Yield Strength

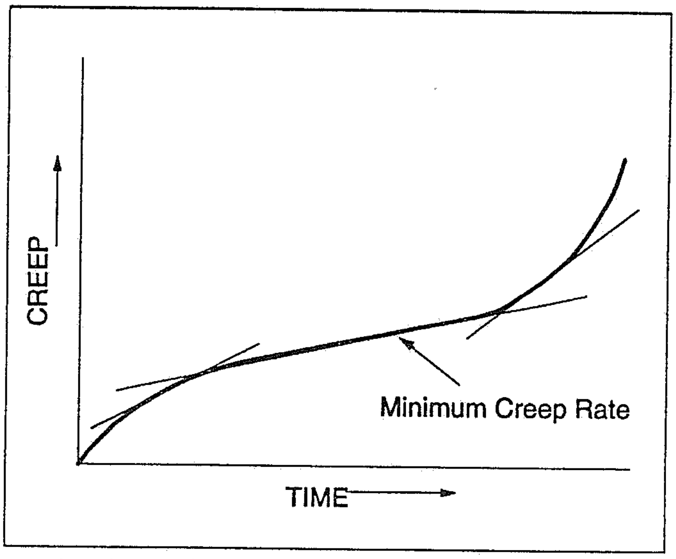
Stress which causes a material to exhibit a specified deformation. Usually determined from the stress-strain diagram obtained in a compression test. See also yield strength.

Constant Amplitude

Digital function in the Model 8500 that maintains the amplitude of the command signal during changes in frequency of the signal.

Creep

Deformation that occurs over a period of time when a material is subjected to constant stress at constant temperature. In metals, creep usually occurs only at elevated temperatures. Creep at room temperature is more common in plastic materials and is called cold flow or deformation under load.



Data obtained in a creep test usually is presented as a plot of creep vs. time with stress and temperature constant. Slope of the curve is creep rate and end point of the curve is time for rupture. As indicated in the accompanying diagram, the creep of a material can be divided into three stages. First stage, or primary creep, starts at a rapid rate and slows with time. Second stage (secondary) creep has a relatively uniform rate. Third stage (tertiary) creep has an accelerating creep rate and terminates by failure of material at time for rupture. See also stress-relaxation.

Creep Limit

Alternate term for creep strength.

Creep Rate

Time rate of deformation of a material subject to stress at a constant temperature. It is the slope of the creep vs. time diagram obtained in a creep test. Units usually are in/in/hr or % of elongation/hr. Minimum creep rate is the slope of the portion of the creep vs. time diagram corresponding to secondary creep.

Creep Recovery

Rate of decrease in deformation that occurs when load is removed after prolonged application in a creep test. Constant temperature is maintained to eliminate effects of thermal expansion, and measurements are taken from time load is zero to eliminate elastic effects.

Creep Rupture Strength

Stress required to cause fracture in a creep test within a specified time. Alternate term is stress rupture strength.

Creep Strength

Maximum stress required to cause a specified amount of creep in a specified time. Also used to describe maximum stress that can be generated in a material at constant temperature under which creep rate decreases with time. An alternate term is creep limit.

Creep Test

Method for determining creep or stress relaxation behavior. To determine creep properties, material is subjected to prolonged constant tension or compression loading at constant temperature. Deformation is recorded at specified time intervals and a creep vs. time diagram is plotted. Slope of curve at any point is creep rate. If failure occurs, it terminates test and time for rupture is recorded. If specimen does not fracture within test period, creep recovery may be measured. To determine stress relaxation of material, specimen is deformed a given amount and decrease in stress over prolonged period of exposure at constant temperature is recorded. Standard creep testing procedures are detailed in ASTM E-139, ASTM D-2990 and D-2991 (plastics) and ASTM D-2294 (adhesives).

Crush Resistance

Load required to produce fracture in a glass sphere subjected to crush loading. (ASTM D-1213).

Crushing Load

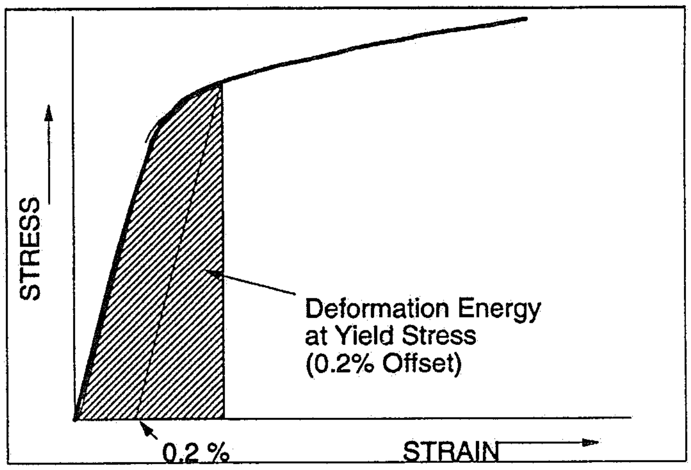
Maximum compressive force applied during a compression or crushing test. For materials that do not shatter, crushing load is defined as the force required to produce a specified type of failure.

Crushing Strength

Compressive load required to cause a crack to form in a sintered metal powder bearing (ASTM B-438 and B-439). Cold crushing strength of refractory bricks and shapes is the gross compressive stress required to cause fracture. (ASTM C-133).

Deformation Energy

Energy required to deform a material a specified amount. It is the area under the stress-strain diagram up to a specified strain, as shown in the following diagram.



Deformation Under Load

Measure of the ability of rigid plastics to withstand permanent deformation and the ability of nonrigid plastics to return to original shape after deformation. Standard test methods for determining both types of deformation under load are given in ASTM D-621. For rigid plastics, deformation (which can be flow or flow and shrinkage) is reported as % change in height of specimen after 24 hours under a specified load. For nonrigid plastics, results are reported as % change in height after 3 hours under load and recovery in the 1-1/2 hour period following removal of the load. Recovery is % increase in height calculated on basis of original height.

Delamination Strength

Measure of the node-to-node bond strength of honeycomb core materials. It is equal to the tensile load applied to a honeycomb panel at fracture divided by its width times its thickness (ASTM C-363).

Dry Strength

Strength of an adhesive joint determined immediately after drying or after a period of conditioning in a specified atmosphere. (ASTM D-2475).

Ductility

Extent to which a material can sustain plastic deformation without rupture. Elongation and reduction of area are common indices of ductility.

Dynamic Creep

Creep that occurs under fluctuating load or temperature.

EASL

Elongation at a specified load.

Eccentricity of Loading

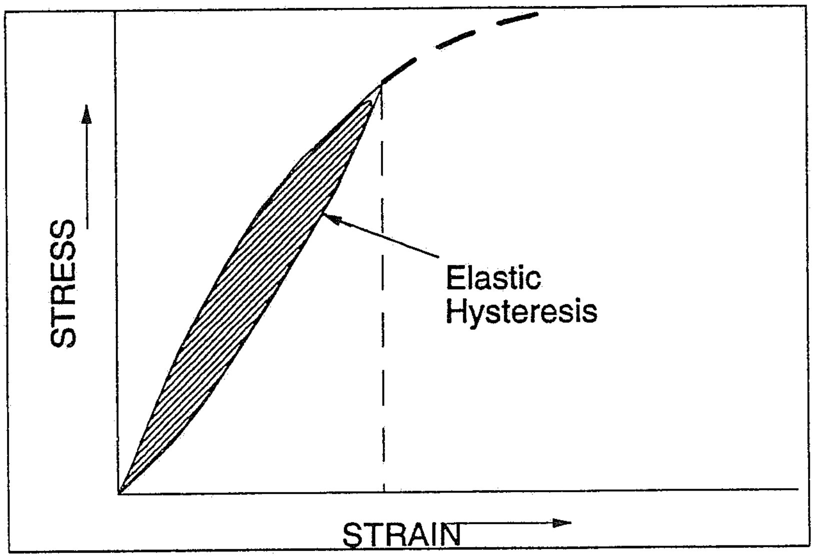
Distance between the actual line of action of compressive or tensile loads and the line of action that would produce a uniform stress over the cross section of the specimen.

Edge Tearing Strength

Measure of the resistance of paper to tearing when folded over a V-notch beam and loaded in a tensile testing machine. Results are reported in lb or kg. (See Tear Resistance.)

Elastic Hysteresis

Difference between strain energy required to generate a given stress in a material and elastic energy at that stress. It is the energy dissipated as heat in a material in one cycle of dynamic testing. Elastic hysteresis divided by elastic deformation energy is equal to damping capacity.

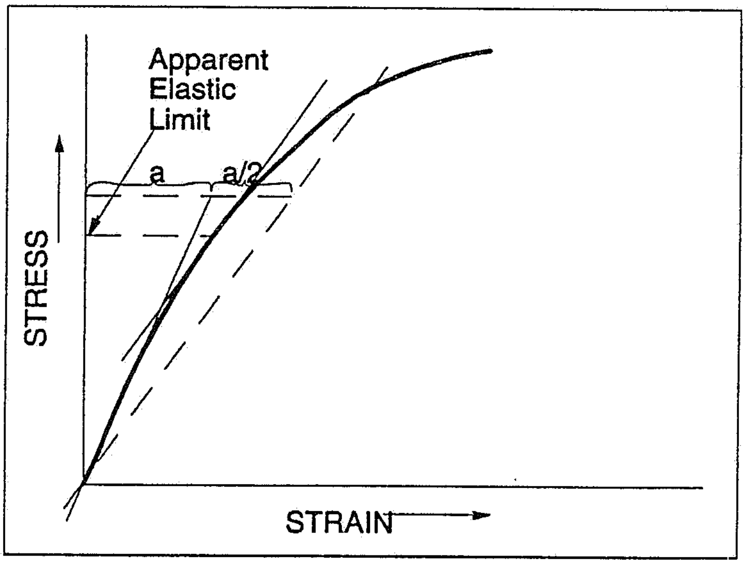


Elastic Limit

Greatest stress that can be applied to a material without causing permanent deformation. For metals and other materials that have a significant straight line portion in their stress/strain diagram, elastic limit is approximately equal to proportional limit. For materials that do not exhibit a significant proportional limit, elastic limit is an arbitrary approximation (the apparent elastic limit).

Elastic Limit, Apparent

Arbitrary approximation of the elastic limit of materials that do not have a significant straight line portion on a stress/strain diagram. It is equal to the stress at which the rate of strain is 50% greater than at zero stress. It is the stress at the point of tangency between the stress-strain curve and the line having a slope, with respect to the stress axis, 50% greater than the slope of the curve at the origin.



Elasticity

Ability of a material to return to its original shape when load causing deformation is removed.

Elongation

Measure of the ductility of a material determined in a tension test. It is the increase in gage length (measured after rupture) divided by original gage length. Higher elongation indicates higher ductility. Elongation cannot be used to predict behavior of materials subjected to sudden or repeated loading.

Embrittlement

Reduction in ductility due to physical or chemical changes.

Endurance

Alternate term for fatigue limit.

Engineering Stress

Load applied to a specimen in a tension or compression test divided by the cross-sectional area of the specimen. The change in cross-sectional area that occurs with increases and decreases in applied load, is disregarded in computing engineering stress. It is also called conventional stress.

Event Detector

Digital function in the Model 8500 that looks for and trips on certain events, such as maximum peak, minimum peak, underpeak, overpeak, and specimen break. Can perform a number of actions, such as stop, hold, unload, transfer control mode, etc. upon trip. It is not used as a safety limit.

Extensometer

Instrument for measuring changes in linear dimensions. Also called a strain gauge. Frequently based on strain gauge technology.

Fatigue

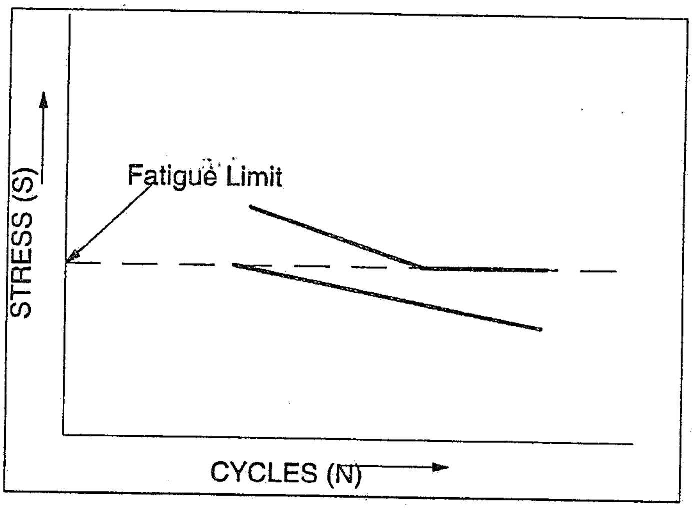
Permanent structural change that occurs in a material subjected to fluctuating stress and strain. However, in the case of glass, fatigue is determined by long-term static testing and is analogous to stress rupture in other materials. In general, fatigue failure can occur with stress levels below the elastic limit.

Fatigue Life

Number of cycles of fluctuating stress and strain of a specified nature that a material will sustain before failure occurs. Fatigue life is a function of the magnitude of the fluctuating stress, geometry of the specimen and test conditions. An S-N diagram is a plot of the fatigue life at various levels of fluctuating stress.

Fatigue Limit

Maximum fluctuating stress a material can endure for an infinite number of cycles. It is usually determined from an S-N diagram and is equal to the stress corresponding to the asymptote of the locus of points corresponding to the fatigue life of a number of fatigue test specimens. An alternate term is endurance limit.



Fatigue Notch Factor

Ratio of fatigue strength of a specimen with no stress concentration to fatigue strength of a specimen with a notch or other stress raisers. Fatigue notch factor is usually lower than the theoretical stress concentration factor because of stress relief due to plastic deformation. An alternate term is strength reduction ratio.

Fatigue Ratio

Ratio of fatigue strength or fatigue limit to tensile strength. For many materials, fatigue ratio may be used to estimate fatigue properties from data obtained in tension tests.

Fatigue Strength

Magnitude of fluctuating stress required to cause failure in a fatigue test specimen after a specified number of cycles of loading. Usually determined directly from the S-N diagram.

Fatigue Strength Reduction Factor

An alternate term for fatigue notch factor.

Fatigue Test

A method for determining the behavior of materials under fluctuating loads. A specified mean load (which may be zero) and an alternating load are applied to a specimen and the number of cycles required to produce failure (fatigue life) is recorded. Generally, the test is repeated with identical specimens and various fluctuating loads. Loads may be applied axially, in torsion, or in flexure. Depending on amplitude of the mean and cyclic load, net stress in the specimen may be in one direction through the loading cycle, or may reverse direction.

Data from fatigue testing often are presented in an S-N diagram which is a plot of the number of cycles required to cause failure in a specimen against the amplitude of the cyclical stress developed. The cyclical stress represented may be stress amplitude, maximum stress or minimum stress. Each curve in the diagram represents a constant mean stress.

Most fatigue tests are conducted in flexure, rotating beam, or vibratory type machines. Fatigue testing is generally discussed in "Manual on Fatigue Testing," ASTM STP 91-A, and "Mechanical Testing of Materials," A.J. Fenner, Philosophical Library, Inc. ASTM D-671 details a standard procedure for fatigue testing of plastics in flexure.

Fiber Stress

Stress through a point in a part in which stress distribution is not uniform. For example, the stress in a beam under bending load varies from compression to tension across the beam. It is more meaningful in determining the properties of the beam material to consider the maximum stress generated in the outer fibers of the beam. Similarly, stress in a beam under twist loading is a maximum in the material furthest from the axis of twist.

Flex Resistance

Ability of foam rubber to sustain repeated compressive loads without damage to cell structure. (ASTM D-1055).

Flexural Modulus of Elasticity

Alternate term for modulus in bending.

Flexural Strength

Maximum fiber stress developed in a specimen just before it cracks or breaks in a flexure test. Flexural yield strength is reported instead of flexural strength for materials that do not crack in the flexure test. An alternate term is modulus of rupture.

Flexure Test

Method for measuring behavior of materials subjected to simple beam loading. It is also called a transverse beam test with some materials. Specimen is supported on two knife edges as a simple beam and load is applied at its midpoint. Maximum fiber stress and maximum strain are calculated for increments of load. Results are plotted in a stress-strain diagram, and maximum fiber stress at failure is flexural strength. Flexural yield strength is reported for materials that do not crack. Standard test procedures are given in ASTM D-790 (plastics) and ASTM C-674 (fired whiteware). ASTM D-797 (elastomers), ASTM A-438 (cast iron) and ASTM D-86 (glass).

Flow Stress

Stress required to cause plastic deformation.

Fracture Stress

True stress generated in a material at fracture.

Fracture Test

Visual test wherein a specimen is fractured and examined for grain size, case depth, etc.

Fracture Toughness

Ability of a material to resist crack propagation when subjected to shock load as in an impact test.

Hardness

Measure of a material's resistance to localized plastic deformation. Most hardness tests involve indentation, but hardness may be reported as resistance to scratching (file test), or rebound of a projectile bounced off the material (scleroscope hardness). Some common measures of indentation hardness are Brinell Hardness Number, Rockwell Hardness Number, ASTM Hardness Number, Diamond Pyramid Impact Test Hardness Number, Durometer Hardness, Knoop Hardness, and Pfund Hardness. A table relating various types of hardness values of metals is given in ASTM E-140. Hardness often is a good indication of tensile and wear properties of a material.

Hooke's Law

Stress is directly proportional to strain. Hooke's law assumes perfectly elastic behavior. It does not take into account plastic or dynamic loss properties.

Impact Energy

Energy required to fracture a part subjected to shock loading as in an impact test. Alternate terms are impact value, impact strength, impact resistance, and energy absorption.

Impact Strength

Energy required to fracture a specimen subjected to shock loading, as in an impact test. Alternate terms are impact energy, impact value, impact resistance and energy absorption. It is an indication of the toughness of the material.

Impact Test

A method for determining behavior of material subjected to shock loading in bending, tension, or torsion. The quantity usually measured is the energy absorbed in breaking the specimen in a single blow, as in the Charpy Impact Test, Izod Impact Test, and Tension Impact Test. Impact tests also are performed by subjecting specimens to multiple blows of increasing intensity, as in the drop ball impact test, and repeated blow impact test. Impact resilience and scleroscope hardness are determined in nondestructive impact tests.

Kink Test

Method for determining ductility of metal wire. A short section of wire is looped and drawn in tension to produce a kink. Relative ductility is indicated by the occurrence or non-occurrence of failure and extent to which kink may be opened up without failure.

Knot Strength

Tenacity of a fiber in which an overhand knot is tied. Knot strength is a measure of a fiber's sensitivity to compressive and shear stresses.

LASE

Load At Specified Elongation.

Limits

Safety function in the Model 8500 that suspends operation or shuts off the system when safety bounds, set by the operator, are exceeded during testing operations. They are used to prevent injury to operating personnel and to prevent damage to the testing system or expensive test specimens.

Load-Deflection Diagram

Plot of load versus corresponding deflection.

Load Protect

Safety feature in the Model 8500 that prevents the load value from exceeding a preset value when in position control. When Load Protect is on, the actuator will stall if commanded to move outside the preset load bound. It is used to protect delicate specimens when moving the actuator or when closing grips. It functions only in position control.

Maximum Fiber Stress

Maximum tensile or compressive stress in a homogeneous flexure or torsion test specimen. For a specimen loaded as a simple beam at its midpoint, maximum fiber stress occurs at mid-span and may be calculated by the formula (for rectangular specimens):

$$S = \frac{3PL}{2bd^2}$$

where S is maximum fiber stress; P, load; L, span; b, width of the beam; and d, depth of the beam. For a circular cross section member loaded in torsion, maximum fiber stress may be calculated by the following formula:

$$S = \frac{Tr}{J}$$

where T is twisting moment; r, original outer radius and J, polar moment of inertia of original cross section.

Mean Stress

Algebraic difference between maximum and minimum stress in one cycle of fluctuating loading, as in a fatigue test. Tensile stress is considered positive and compressive stress negative.

Minimum Bend Radius

Minimum radius to which a sheet or wire can be bent to a specified angle without failure.

Modulus

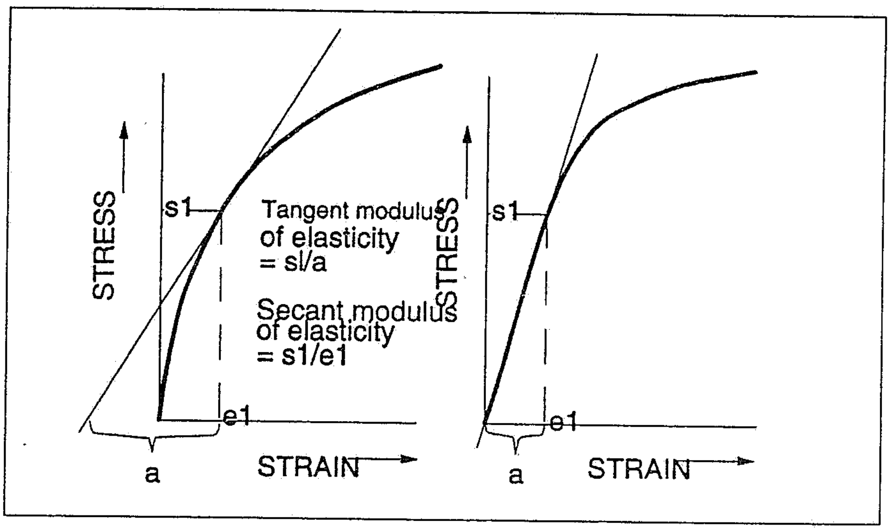
Alternate term for modulus of elasticity, often used in connection with rubber.

Modulus in Bending

Ratio of maximum fiber stress to maximum strain, within elastic limit of stress-strain diagram obtained in flexure test. Alternate term is flexural modulus of elasticity.

Modulus of Elasticity

Rate of change of strain as a function of stress. The slope of the straight line portion of a stress-strain diagram. Tangent modulus of elasticity is the slope of the stress-strain diagram at any point. Secant modulus of elasticity is stress divided by strain at any given value of stress or strain. It also is called stress-strain ratio. Tangent and secant modulus of elasticity are equal, up to the proportional limit of a material. Depending on the type of loading represented by the stress-strain diagram, modulus of elasticity may be reported as: compressive modulus of elasticity (or modulus of elasticity in compression); flexural modulus of elasticity (or modulus of elasticity in flexure); shear modulus of elasticity (or modulus of elasticity in shear); tensile modulus of elasticity (or modulus of elasticity in tension); or torsional modulus of elasticity (or modulus of elasticity in torsion). Modulus of elasticity may be determined by dynamic testing, where it can be derived from complex modulus.



Modulus used alone generally refers to tensile modulus of elasticity. Shear modulus is almost always equal to torsional modulus and both are called modulus of rigidity. Moduli of elasticity in tension and compression are approximately equal and are known as Young's modulus. Modulus of rigidity is related to Young's modulus by the equation:

$$E = 2G(1+r)$$

where E is Young's modulus (psi), G is modulus of rigidity (psi) and r is Poisson's ratio. Modulus of elasticity also is called elastic modulus and coefficient of elasticity.

Modulus of Rigidity

Rate of change of strain as a function of stress in a specimen subjected to shear or torsion loading. It is the modulus of elasticity determined in a torsion test. Alternate terms are modulus of elasticity in torsion and modulus of elasticity in shear.

Apparent modulus of rigidity is a measure of the stiffness of plastics measured in a torsion test (ASTM D-1043). It is “apparent” because the specimen may be deflected past its proportional limit and the value calculated may not represent the true modulus of elasticity within the elastic limit of the material.

Modulus of Rupture

Ultimate strength determined in a flexure or torsion test. In a flexure test, modulus of rupture in bending is the maximum fiber stress at failure. In a torsion test, modulus of rupture in torsion is the maximum shear stress in the extreme fiber of a circular member at failure. Alternate terms are flexural strength and torsional strength.

Modulus of Strain Hardening

Alternate term for rate of strain hardening.

Modulus of Toughness

The work done on a unit volume of material as a simple tensile force is gradually increased from zero to the value causing rupture is defined as the Modulus of Toughness. This may be calculated as the entire area under the stress-strain curve from the origin to rupture. Toughness of a material is its ability to absorb energy in the plastic range of the material.

Necking

Localized reduction of cross-sectional area of a specimen under tensile load. It is disregarded in calculating engineering stress but is taken into account in determining true stress.

Nominal Stress

Stress calculated on the basis of the net cross section of a specimen without taking into account the effect of geometric discontinuities such as holes, grooves, fillets, etc.

Offset Yield Strength

Arbitrary approximation of elastic limit. It is the stress that corresponds to the point of intersection of a stress-strain diagram and a line parallel to the straight line portion of the diagram. Offset refers to the distance between the origin of the stress-strain diagram, and the point of intersection of the parallel line and the 0 stress axis. Offset is expressed in terms of strain (often 0.2%).

Operating Stress

Stress imposed on a part in service.

Overstressing

Application of high fluctuating loads at the beginning of a fatigue test and lower loads toward the end. It is a means for speeding up a fatigue test.

Peel Resistance

Torque required to separate an adhesive and adherend in the climbing drum peel test (ASTM D-1781). It is a measure of bond strength.

Peel Strength

Measure of the strength of an adhesive bond. It is the average load per unit width of bond line required to part bonded materials where the angle of separation is 180 degrees and separation rate is 6 in/min (ASTM D-903).

Plastic Deformation

Deformation that remains after the load causing it is removed. It is the permanent part of the deformation beyond the elastic limit of a material. It also is called plastic strain and plastic flow.

Plasticity

Tendency of a material to remain deformed, after reduction of the deforming stress, to a value equal to or less than its yield strength.

Plasticity Number

Index of the compressibility of rubber at elevated temperatures. Equal to 100 times the height of a standard specimen, after a 3 to 10 minute compression by a 5 kg load (ASTM D-926).

Poisson's Ratio

Ratio of lateral strain to axial strain in an axial loaded specimen. It is the constant that relates modulus of rigidity to Young's modulus in the equation:

$$E = 2G(r+1)$$

where E is Young's modulus; G, modulus of rigidity; and r, Poisson's ratio. The formula is valid only within the elastic limit of a material. A method for determining Poisson's ratio is given in ASTM E-132.

Proof Stress

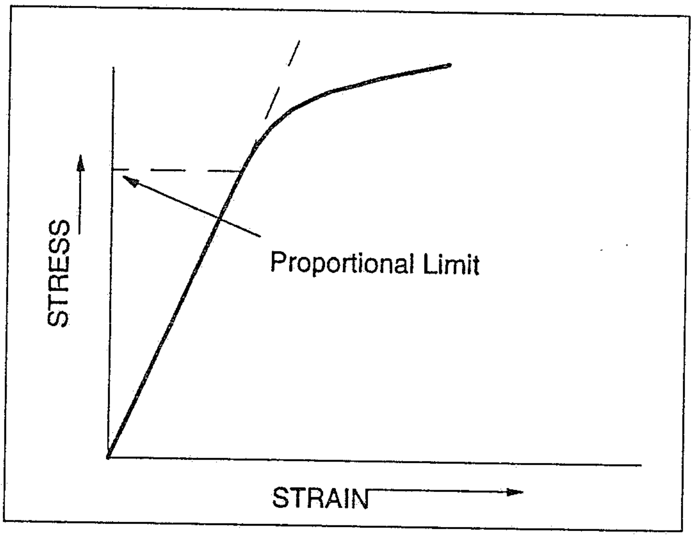
Stress that will cause a specified permanent deformation.

Proportional Limit

Highest stress at which stress is directly proportional to strain. It is the highest stress at which the curve in a stress-strain diagram is a straight line. Proportional limit is equal to elastic limit for many metals.

Rate of Strain Hardening

Rate of change of true stress as a function of true strain in a material undergoing plastic deformation. An alternate term is modulus of strain hardening.



Recovery

Index of a material's ability to recover from deformation in the compressibility and recovery test (ASTM F-36), the deformation under load test (ASTM D-621) and the plastometer test (ASTM D-926). In the compressibility and recovery test, it usually is reported with compressibility and given as %. It is calculated by dividing the difference between recovered thickness and thickness under load, by the difference between original thickness and thickness under load. In the deformation under load test, it indicates the extent to which a nonrigid plastic recovers from prolonged compressive deformation at an elevated temperature. It is given as %, and is calculated by dividing the difference between height recovered 1-1/2 hours after load is removed and height after three hours of loading, by the change in height under load. In the plastometer test, it indicates the extent to which an elastomer recovers from compressive loading at an elevated temperature. It is equal to plasticity number minus recovered height.

Recovery Test

Method for measuring compressibility and recovery of gasket and seal materials (ASTM F-36).

Reduction of Area

Measure of the ductility of metals obtained in a tension test. It is the difference between original cross sectional area of a specimen and the area of its smallest cross section after testing. It is usually expressed as % decrease in original cross section. The smallest cross section can be measured at or after fracture. For metals, it usually is measured after fracture and for plastics and elastomers, it is measured at fracture.

Relative Modulus

Ratio of the modulus of a rubber at a given temperature to its modulus at 73° F. It is determined in the Gehman torsional test.

Relaxation

Rate of reduction of stress in a material due to creep. An alternate term is stress relaxation.

Residual Elongation

Measure of ductility of plastics. It is the elongation of a plastic specimen measured 1 minute after rupture in a tension test.

Rupture Resistance

Indication of ability of rubber to withstand tensile loading. It is the load required to rupture a rubber specimen under conditions set out in ASTM D-530.

Rupture Strength

Nominal stress developed in a material at rupture. It is not necessarily equal to ultimate strength. And, since necking is not taken into account in determining rupture strength, it seldom indicates true stress at rupture.

S-N Diagram

Plot of stress (S) against the number of cycles (N) required to cause failure of similar specimens in a fatigue test. Data for each curve on an S-N diagram are obtained by determining fatigue life of a number of specimens subjected to various amounts of fluctuating stress. The stress axis can represent stress amplitude, maximum stress or minimum stress. A log scale is almost always used for the N scale and sometimes for the S scale.

Secant Modulus of Elasticity

Ratio of stress to strain at any point on curve in a stress-strain diagram. It is the slope of a line from the origin to any point on a stress-strain curve.

Set Point

Arithmetic mean of the excursions of the controlling waveform in the Model 8500; i.e., the algebraic sum of the positive and negative amplitudes of the waveform. It is roughly equivalent to "mean level" on earlier Instron Servohydraulic Testing Systems.

Shear Modulus of Elasticity

Tangent or secant modulus of elasticity of a material subjected to shear loading. Alternate terms are modulus of rigidity and modulus of elasticity in shear. Also, shear modulus of elasticity usually is equal to torsional modulus of elasticity. A method for determining shear modulus of elasticity of structural materials by means of a twisting test is given in ASTM E-143. A method for determining shear modulus of structural adhesives is given in ASTM E-229.

Shear Strength

Maximum shear stress that can be sustained by a material before rupture. It is the ultimate strength of a material subjected to shear loading. It can be determined in a torsion test where it is equal to torsional strength. The shear strength of a plastic is the maximum load required to shear a specimen in such a manner that the resulting pieces are completely clear of each other. It is reported in psi based on the area of the sheared edge (ASTM D-732). The shear strength of a structural adhesive is the maximum shear stress in the adhesive prior to failure under torsional loading (ASTM E-229). Methods for determining shear strength of timber are given in ASTM D-143 and ASTM D-198.

Splitting Resistance

Measure of the ability of felt to withstand tearing. It is the load required to rupture a slit felt specimen by gripping lips of the cut in jaws and pulling them apart (ASTM D-461). An alternate term is tear resistance.

Springback

Degree to which a material returns to its original shape after deformation. In plastics and elastomers, it is also called recovery.

Stiffness

Measure of resistance of plastics to bending. It includes both plastic and elastic behavior, so it is an apparent value of elastic modulus rather than a true value (ASTM D-747).

Strain

Change per unit length in a linear dimension of a part or specimen, usually expressed in % Strain, as used with most mechanical tests, is based on original length of the specimen.

True or natural strain is based on instantaneous length, and is equal to: $\ln \cdot \frac{l}{l_o}$, where l is instantaneous length and l_o is original length of the specimen. Shear strain is the change in angle between two lines originally at right angles.

Strain Energy

Measure of energy absorption characteristics of a material under load up to fracture. It is equal to the area under the stress-strain curve, and is a measure of the toughness of a material.

Strain Hardening Exponent

Measure of increase in hardness and strength caused by plastic deformation. It is related to true stress and true strain by the equation:

$$\sigma = \sigma_0 \delta^{\eta}$$

where σ is true stress, σ_0 is true stress at unit strain, δ is true strain and η is strain hardening exponent.

Strain Point

Temperature at which internal stress in glass is substantially relieved in about 1 hour. (ASTM C-336).

Strain Rate

Time rate of elongation.

Strain Relaxation

Alternate term for creep of rubber.

Strength Reduction Ratio

Alternate term for fatigue notch factor.

Stress

Load on a specimen divided by the area through which it acts. As used with most mechanical tests, stress is based on original cross-sectional area without taking into account changes in area due to applied load. This sometimes is called conventional or engineering stress. True stress is equal to the load divided by the instantaneous cross-sectional area through which it acts.

Stress Amplitude

One-half the range of fluctuating stress developed in a specimen in a fatigue test. Stress amplitude often is used to construct an S-N diagram.

Stress Concentration Factor

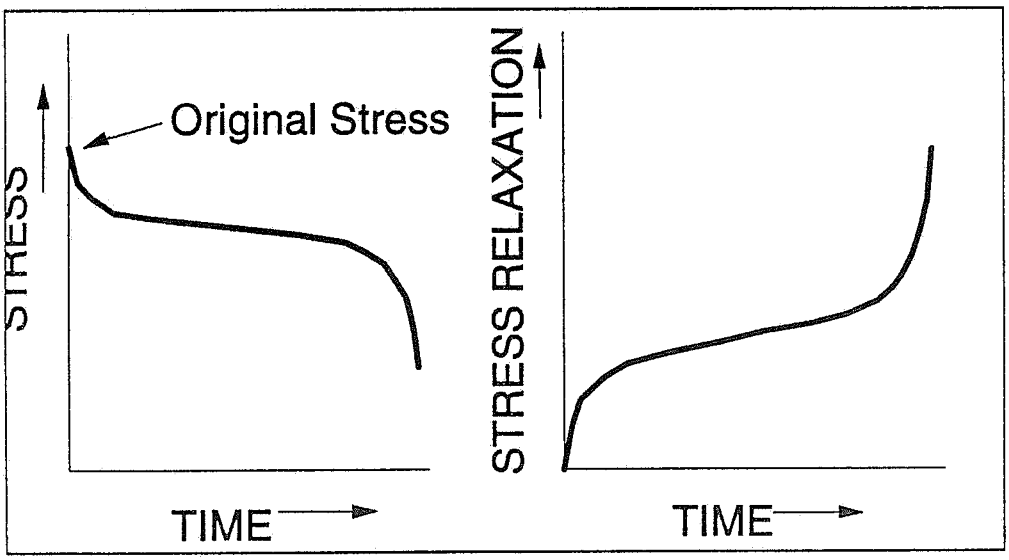
Ratio of the greatest stress in the area of a notch or other stress raiser to the corresponding nominal stress. It is a theoretical indication of the effect of stress concentrators on mechanical behavior. Stress concentration factor usually is higher than the empirical fatigue notch factor or strength reduction ratio, because it does not take into account stress relief due to local plastic deformation.

Stress Ratio

Ratio of minimum stress to maximum stress in one cycle of loading in a fatigue test. Tensile stresses are considered positive and compressive stresses negative.

Stress Relaxation

Decrease in stress in a material subjected to prolonged constant strain at a constant temperature. Stress relaxation behavior is determined in a creep test. Data often is presented in the form of a stress vs. time plot. Stress relaxation rate is the slope of the curve at any point.

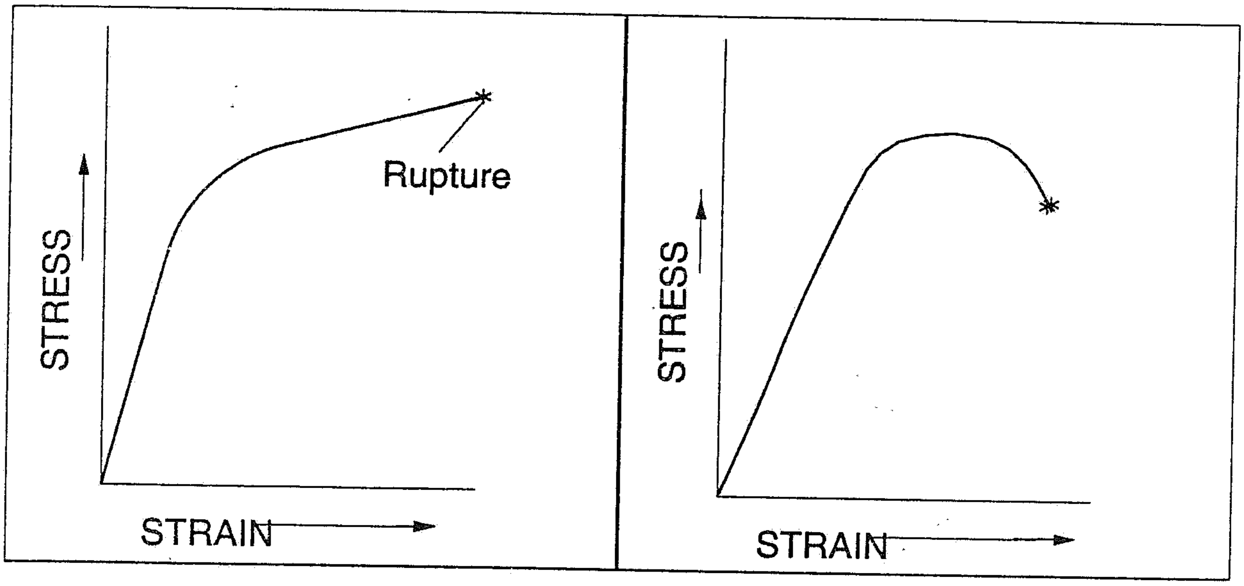


Stress Rupture Strength

Alternate term for creep strength.

Stress-Strain Diagram

Graph of stress as a function of strain. It can be constructed from data obtained in any mechanical test where load is applied to a material, and continuous measurements of stress and strain are made simultaneously. It is constructed for compression, tension and torsion tests. An example is shown below.



Stress-Strain Ratio

Stress divided by strain at any load or deflection. Below the elastic limit of a material, it is equal to tangent modulus of elasticity. An alternate term is the secant modulus of elasticity.

Stripping Strength

Alternate term for peel strength.

Tangent Modulus of Elasticity

The instantaneous rate of change of stress as a function of strain. It is the slope at any point on a stress-strain diagram.

Tear Length

Measure of the drawability of sheet metal. Two small parallel slots are cut in the edge of the sheet to form a tab which is gripped and torn from the sheet. The variation in length of tabs torn in different directions is an indication of crystal orientation in the sheet (tabs torn in the direction of orientation are longer). The degree of orientation is an indication of difficulty to be expected in drawing the sheet to uniform shapes.

Tear Resistance

Measure of the ability of sheet or film materials to resist tearing. For paper, it is the force required to tear a single ply of paper after the tear has been started.

Three standard methods are available for determining tear resistance of plastic films: ASTM D-1004 details a method for determining tear resistance at low rates of loading; a test in ASTM D-1922 measures the force required to propagate a pre-cut slit across a sheet specimen; and ASTM D-1038 gives a method for determining tear propagation resistance that is recommended for specification acceptance testing only.

Tear resistance of rubber is the force required to tear a 1 inch thick specimen under the conditions outlined in ASTM D-624. Tear resistance of textiles is the force required to propagate a single-rip tongue-type tear (starting from a cut) by means of a falling pendulum apparatus (ASTM D-1424).

Tearing Strength

Tensile force required to rupture a pre-slit woven fabric specimen under the conditions outlined in ASTM D-2261 and ASTM D-2262. Edge tearing strength of paper is the force required to tear a specimen folded over a V-notch and loaded in a tensile test machine.

Tenacity

Force required to break a yarn or filament, expressed in grams per denier. It is equal to breaking strength divided by denier.

Tensile Modulus of Elasticity

Tangent or secant modulus of elasticity of a material subjected to tensile loading. Alternate terms are Young's modulus and modulus of elasticity in tension. It can be measured in a tension test or in a dynamic test where it is related to resonant frequency on a cylindrical rod by the equation:

$$E = \frac{4\pi^2 l^2 \rho f^2}{k^2 j^4}$$

where E is modulus of elasticity; l, length of the rod; ρ, density; f, resonant frequency; k, radius of gyration of the rod about an axis normal to the rod axis and plane of motion (d/4 for cylindrical rods); and j, a constant dependent on the mode of vibration. Tensile modulus of elasticity is approximately equal to compressive modulus of elasticity within the proportional limit.

Tensile Strength

Ultimate strength of a material subjected to tensile loading. It is the maximum stress developed in a material in a tension test.

Tension Impact Test

Method for determining energy required to fracture a specimen under shock tensile loading (ASTM D-1822).

Tension Set

Extent to which vulcanized rubber is permanently deformed after being stretched a specified amount for a short time. It is expressed as a % of the original length or distance between gage marks (ASTM D-412).

Tension Test

Method for determining behavior of materials under axial stretch loading. Data from test are used to determine elastic limit, elongation, modulus of elasticity, proportional limit, reduction in area, tensile strength, yield point, yield strength and other tensile properties. Tension tests at elevated temperatures provide creep data. Procedures for tension tests of metals are given in ASTM E-8. Methods for tension tests of plastics are outlined in ASTM D-638, ASTM D-2289 (high strain rates), and ASTM D-882 (thin sheets). ASTM D-2343 outlines a method for tension testing of glass fibers; ASTM D-897, adhesives; ASTM D-412, vulcanized rubber.

Time for Rupture

Time required to rupture specimen under constant stress and temperature in a creep test.

Torsion Test

Method for determining behavior of materials subjected to twisting loads. Data from torsion test is used to construct a stress-strain diagram and to determine elastic limit torsional modulus of elasticity, modulus of rupture in torsion, and torsional strength. Shear properties are often determined in a torsion test. (ASTM E-143).

Torsional Deformation

Angular displacement of specimen caused by a specified torque in torsion test. It is equal to the angular twist (radians) divided by the gage length (in.).

Torsional Modulus of Elasticity

Modulus of elasticity of material subjected to twist loading. It is approximately equal to shear modulus and also is called modulus of rigidity.

Torsional Strain

Strain corresponding to a specified torque in the torsion test. It is equal to torsional deformation multiplied by the radius of the specimen.

Torsional Strength

Measure of the ability of a material to withstand a twisting load. It is the ultimate strength of a material subjected to torsional loading, and is the maximum torsional stress that a material sustains before rupture. Alternate terms are modulus of rupture and shear strength.

Torsional Stress

Shear stress developed in a material subjected to a specified torque in torsion test. It is calculated by the equation:

$$S = \frac{Tr}{J}$$

where T is torque, r is the distance from the axis of twist to the outer-most fiber of the specimen, and J is the polar moment of inertia.

True Strain

Instantaneous % of change in length of specimen in mechanical test. It is equal to the natural logarithm of the ratio of length at any instant to original length.

True Stress

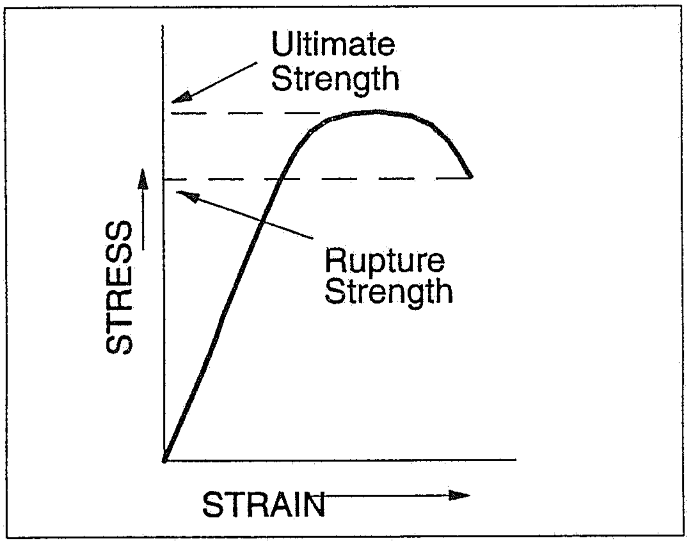
Applied load divided by actual area of the cross section through which load operates. It takes into account the change in cross section that occurs with changing load.

Ultimate Elongation

Alternate term for elongation of material at rupture under tensile loading.

Ultimate Strength

Highest engineering stress developed in material before rupture. Normally, changes in area due to changing load and necking are disregarded in determining ultimate strength.



Wet Strength

Breaking strength of paper saturated with water. Also, the strength of an adhesive bond after immersion in water.

Yield Point

Stress at which strain increases without accompanying increase in stress. Only a few materials (notably steel) have a yield point, and generally only under tension loading.

Yield Point Elongation

Strain at yield point of a material. It is an indication of ductility.

Yield Strength

Indication of maximum stress that can be developed in a material without causing plastic deformation. It is the stress at which a material exhibits a specified permanent deformation and is a practical approximation of elastic limit. Offset yield strength is determined from a stress-strain diagram. It is the stress corresponding to the intersection of the stress-strain curve, and a line parallel to its straight line portion offset by a specified strain. Offset for metals is usually specified as 0.2%, i.e., the intersection of the offset line and the 0-stress axis is at 0.2% strain. Offset for plastics is usually 2%.

Yield Strength Elongation

Strain corresponding to yield strength of material. It is an indication of ductility.

Yield Value

Stress in an adhesive joint at which a marked increase in deformation occurs without an increase in load.

Young's Modulus

Alternate term for modulus of elasticity in tension or compression.

Zero Suppression

Model 8500 feature which shifts the absolute zero of the command waveform to an offset or "apparent" zero. It is used to improve resolution when using a waveform that is small in relation to the full scale range in use. It is also used when the actuator is offset from its normal or absolute zero to accommodate large grips or long specimens.

Index

A

About This Manual, 1-12
Absolute End Point, 3-28
Absolute Hold Ramp, 3-28
Absolute Ramp Waveforms, 3-27
Analog Output Connector, 2-8
Analog Testing Systems, 1-8
Analog vs Digital Control, 1-8
Auto Calibration, 4-7
Auto-Ranging, 3-20, 4-9 to 4-10
    How Auto-Ranging Works, 4-9
    Realtime Automatic Ranging, 4-9
Automatic Ranging, C-9
    Effectiveness of Auto Ranging, C-11
    How Auto Ranging Works, C-10

B

Board Swapping Hints, 9-21 to 9-23
    Master Dynamic Controller Board, 9-21
    Sensor Conditioner Board, 9-22

C

Calibration, 4-5 to 4-8
    Auto Calibration, 4-7
    Calibration Process, 4-5
    Coarse Balance, 4-5
    Electrical Span Calibration, 4-6
    Fine Balance, 4-6
    Manual Calibration, 4-5
    Rebalancing, 4-7
    Restoring Stored Values, 4-8
    Span, 4-6
Closed Loop Control, 5-2
Composite Command, 3-2
Constant Amplitude, 3-44 to 3-48
Constant Amplitude Controller, 3-44
Corporate Manifold and the Docile Mode, 9-1
    Action of the Control Panel, 9-7
    Corporate Manifold States, 9-4
    Hydraulic Schematic of the Manifold, 9-2
    Introduction, 9-2
    Setting Up the Docile Mode, 9-8
    Shorting the Servovalve, 9-8
Cross-Compensation, 10-5
Cyclic Waveforms, 3-6 to 3-17
    Amplitude Scaling, 3-15
    Argument Generation, 3-10
    Cyclic Waveform Generation, 3-6
    Cyclic Waveform Generator States, 3-7
    External Waveforms, 3-13
    Frequency Accuracy, 3-16
    Resolution and Accuracy, 3-15
    Shape Generation, 3-11

  - Sine Wave Accuracy, 3-15
  - Sine Wave Resolution, 3-16
  - Triangle Accuracy and Resolution, 3-16

D

- Data Acquisition Card Description, 2-8
- Demand Hold, 3-35
- Demand Hold Dynamic Considerations, 3-36
- Derivative Gain, 5-7
- Derived Feedback, 4-19
- Digital Data Resolution, C-4
  - Advantages of Automatic Ranging, C-9
  - Comparing Converter and Useable Resolutions, C-5
  - Disadvantages of Fixed Analog Ranging, C-9
  - How Ranging Increases Converter Resolution, C-6
  - Increasing Effective Converter Resolution, C-6
  - Limit on Useable Resolution, C-4
  - Maximum Affordable Resolution, C-4
  - Realtime Automatic Ranging, C-9
- Digital Inputs and Outputs, 2-8
- Digital Testing Systems, 1-9
- Direct Digital Control
  - Benefits, 3-18 to 3-43
- Dither Generation, 5-9
- Docile Mode
  - Description, 9-8
  - Set-up Procedure, 9-11
- Docile Mode Set-up
  - Checking if there is a Problem, 9-10
  - Crosshead-Mounted Actuators, 9-15
  - Dual Servovalves, 9-15
  - Example, 9-17
  - Table-Mounted Actuators, 9-10
  - Use with Non-Corporate Manifolds, 9-16

E

- Event Detectors, 7-12 to 7-36
  - Event Detector Types -Break, 7-18
  - Event Detector Types - Count, 7-20
  - Data Logging Actions, 7-28
  - Event Detector Types - Digital, 7-21
  - Event Detector Types - Error, 7-22
  - Event Detector Access, 7-23
  - Event Detector Actions, 7-26
  - Event Detector States, 7-28
  - Event Detector Types, 7-12
  - Example Test, B-2
  - Event Detector Types - GPIB

Trigger, 7-22
  Event Detector Types - Increment, 7-17
  Programmable Event Detector Command Buffers, 7-32
  Programming Activation of the ED, 7-36
  Programming Command Format, 7-33
  Programming the E.D. Action, 7-35
  Programming the ED Sign, 7-35
  Programming the ED State Reset, 7-33
  Programming the ED Threshold, 7-35
  Programming the ED Type, 7-34
  Programming with the Command Set, 7-32
  Realtime Actions, 7-26
  Status Change Messages, 7-31
  Event Detector Types - Threshold, 7-13
Event Detectors, Purpose, 7-2
Event Detectors, Uses of, 7-2

F

Free Mode, 10-3

G

Glossary, D-1

H

Haver Function Generation, 3-13
High Level Inputs Description, 2-18

I

Integral Gain, 5-6

L

Lag Term, 5-7
Limits
  As a Safety Device, 7-2
  Command Execution on Limit Trip, 7-9
  Description, 7-4
  Global Actions and Lockouts, 7-6
  Limit Action Priorities, 7-7
  Limit Actions, 7-5
  Limit Level, 7-5
  Limit Lock, 7-10
  Limit Monitoring, 7-8
  Limits and Auto Loop Shaping in Load, 7-10
  Limits and the Computer, 7-10
Limits and Event Detectors, Distinction, 7-2
Limits and Event Detectors, Use of, 7-1
Limits, Defined, 7-4
Loop Controller, 5-4 to 5-10
  Derivative Gain, 5-7
  Description, 5-4

  - Dither Generation, 5-9
  - Integral Gain, 5-6
  - Lag Term, 5-7
  - Proportional Gain, 5-5
  - Valve Drive Limiting, 5-9
- Loop Shaping, 5-11 to 5-14
  - Automatic, 5-12
- Low Level Inputs Description, 2-14

M

- Master Dynamic Controller Description, 2-12
- Mean Level, 3-3
- Multi-Axial Systems
  - Command Synchronization, 10-3 to 10-4
  - Cross-Compensation, 10-5 to 10-10
  - Cyclic Waveform Generator, 10-3
  - Example of Using Cross-Compensation, 10-5
  - Free Mode, 10-3
  - Master Waveform Generator, 10-3
  - Ramp Waveform Generator, 10-4
  - Slave Locked Mode, 10-3
  - Slaved Mode, 10-3
  - Table of Cross-Compensation Applications, 10-8

P

- Peak Detection, 4-16 to 4-17
  - Peak Detection Algorithm, 4-16
- Proportional Gain, 5-5

R

- Ramp Waveforms
  - Ramp Generation, 3-24
  - Ramp Generator States, 3-18
  - Ramp Rate Conversion Accuracy and Resolution, 3-25
  - Slowest and Fastest Ramps Speeds, 3-26
- Random Waveforms, 3-30
  - Random Generator Buffers, 3-33
  - Random Waveform Generation, 3-31
  - Random Waveform Generator States, 3-30
- Relative Ramp Group, 3-27

S

- Sampled Data Playback, 3-38
  - Accuracy and Resolution, 3-42
  - Amplitude Scaling and Envelope, 3-41
  - Filter, 3-41
  - Interpolater, 3-40
- Saturation Detection, 4-18
- Sensor Conditioner Card Description, 2-14, 2-17 to 2-20
- Servoloop Control
  - Loop Controller, 5-4

Set Point
  Changed by Ramp Waveforms, 3-4
  Changed by Random Waveforms, 3-5
  Changing Explicitly, 3-3
  Changing with Controller Transitions, 3-4
  Changing with Jog Buttons, 3-4
  Definition, 3-3
Sine Function Generation, 3-11
Slave Locked Mode, 10-3
Slaved Mode, 10-3
Specimen Compliance, 5-11
Square Function Generation, 3-12
Sync-Link Function, 2-8
System
  General Description, 1-6
System Block Diagram Description, 2-3

T

Tower Console Description, 2-7
Transducer Recognition, 4-2, A-2 to A-9
  Calibrating to a Known Sensitivity, A-4
  Calibrating to a Known Strain, 1 Element, A-7
  Calibrating to a Known Strain, 2 Elements, A-6
  Calibrating to a Known Strain, 4 Elements, A-5
  Calibration Resistor Types, A-9
  Calibration Type, A-12
  Choosing CAl and Recognition Code Resistors, A-2
  Choosing Calibration Resistors - Examples, A-8
  Choosing Shunt Calibration Resistor, A-3
  Choosing the Resistors - Theory, A-10 to A-15
  Excitation Level, A-11
  Instron Calibration Service, A-16
  Sensitivity Setting, A-11
  Serial Code, A-12
  Significance of the Code Values, A-11
  Table of Code Values, A-13
  Transducer Connector Schematic Diagram, A-2
Triangle Function Generation, 3-12
True Strain, 4-20
True Stress, 4-20

U

User State Storage, 8-1
  Description, 8-2
  Parameter Defaults, 8-3 to 8-8

V

Valve Drive Limiting, 5-9

W

Waveform Generation
  Resolution, 3-16
Waveform Generator States, 3-8

Z

Zero Suppression, 4-11 to 4-15
  Description, 4-11
  Methods, 4-13