Chapter 4

Experimental Setup

This chapter describes the setup of the seat suspension for laboratory testing for this research at the Advanced Vehicle Dynamics Lab (AVDL) at Virginia Tech. First, the seat test structure will be described. Next, the actuation system used to excite the seat suspension will be described, followed by a description of the excitations used for seat testing. Finally, a description of the data acquisition equipment and data analysis techniques will be presented.

4.1 Seat Test Structure

The seat suspension was tested on the test structure shown in Fig. 4.1. The seat tester was mounted to the floor using a steel 24 x 24 x 1 inch (30 x 30 x 2.54 cm) base plate. The main structure was then built up from the base plate using extruded aluminum from 80/20 Incorporated. The main structure consisted of four vertical posts which guided the upper steel plate in the vertical direction using eight 80/20 linear bearings. This configuration constrained the seat motion to a single degree of freedom in the vertical direction. An MTS hydraulic actuator was mounted to the base plate and upper plate to provide the excitation force to the seat base, which was attached to the upper plate. The mating interface between the upper plate and the seat base was designed with slots machined in the upper plate running perpendicular to the slots in the 80/20 seat mounts, as shown in Fig. 4.2, so that seats with different bolt patterns at the base can be mounted for testing.

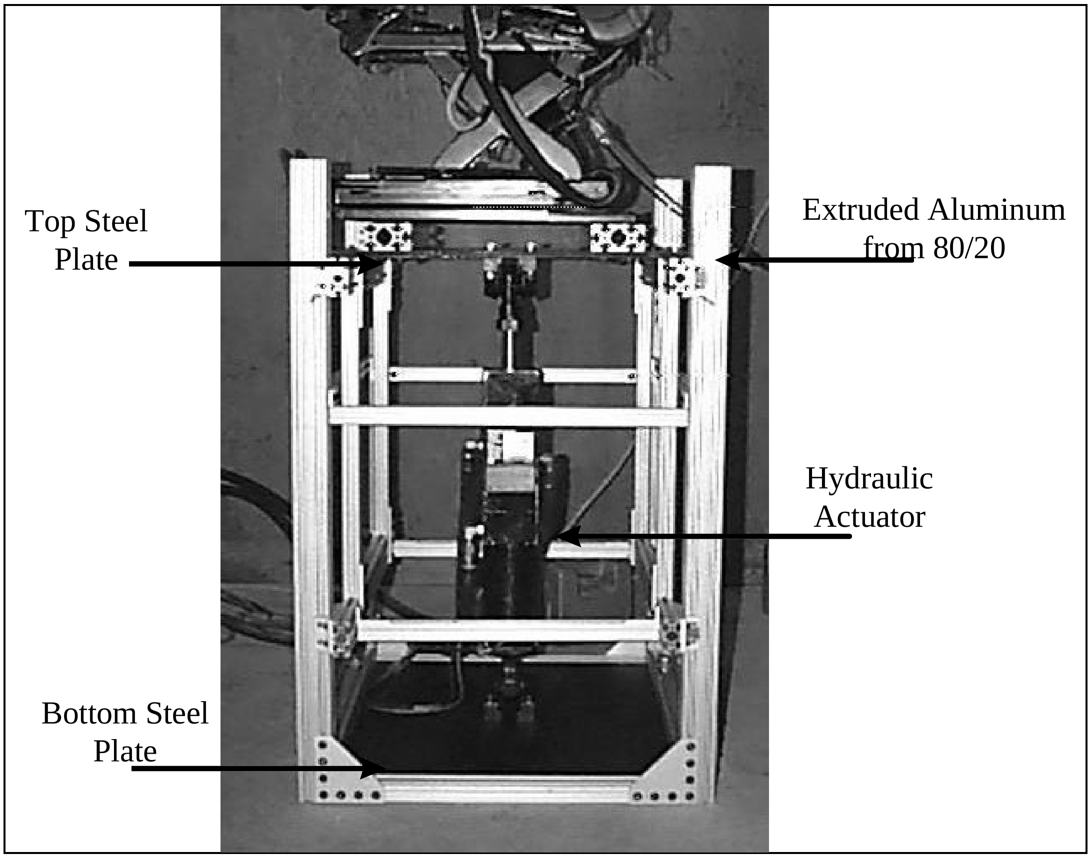

Figure 4.1. Virginia Tech AVDL Seat Tester.

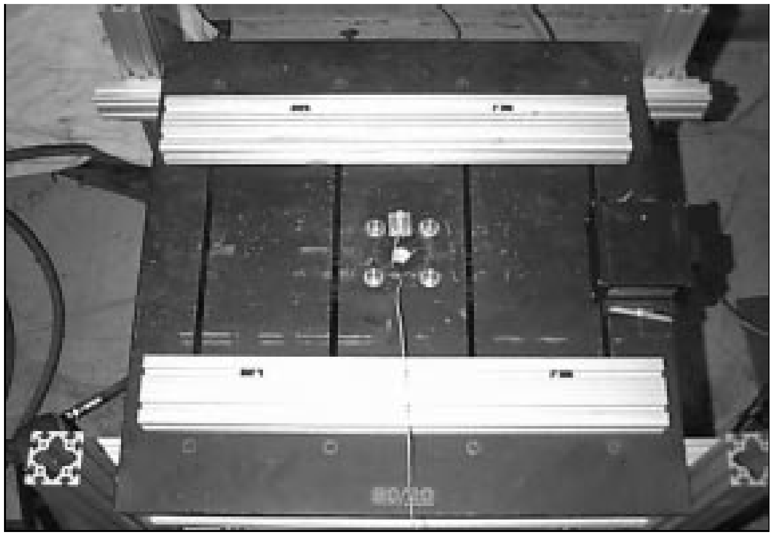

Figure 4.2. Universal Seat Mount.

4.2 Actuation System

In order to excite the seat suspension as if it were mounted in a vehicle, a hydraulic actuation system consisting of a hydraulic pump, manifold, and actuator was mounted to the seat test structure. The hydraulic system is manufactured by Materials Testing System (MTS). A Hydraulic Power Supply, model 502.020, similar to the one shown in Fig. 4.3, was used to provide fluid to the manifold at the rate of 6 gallons per minute (GPM or 24 ℓ/min) with 3000 psi (21 MPa) pressure. A model 263 Hydraulic Service Manifold, shown in Fig. 4.4, was used to interface the hydraulic power supply to the actuator. The primary roll of the manifold is to regulate the hydraulic pressure and flow to the actuator. A regulated flow is needed to ensure proper dynamic response of the hydraulic actuator.

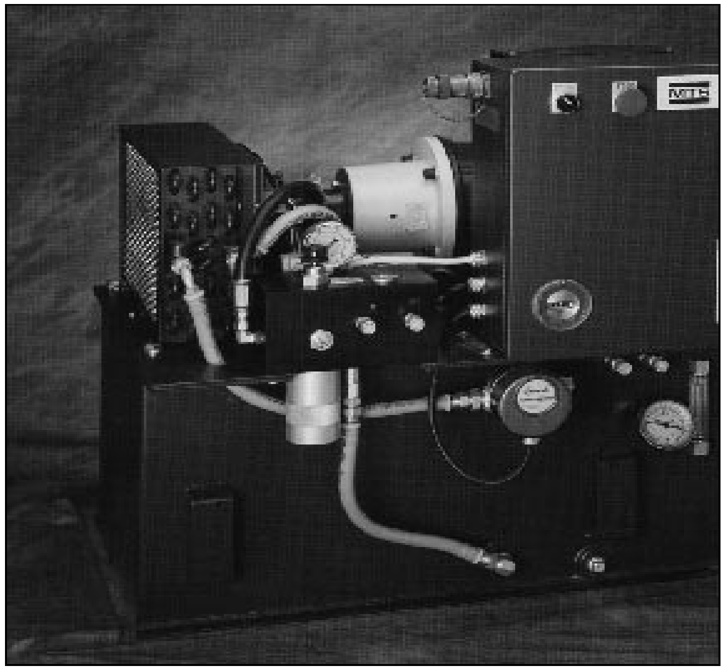

Figure 4.3. MTS 502 Hydraulic Power Supply.

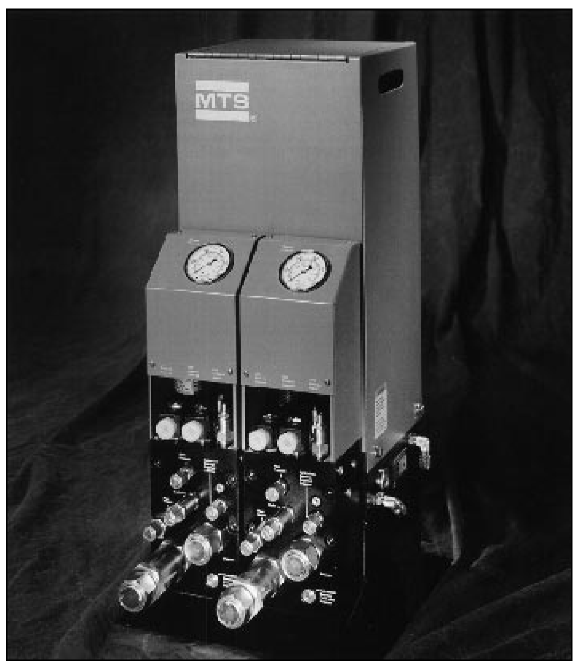

Figure 4.4 Hydraulic Service Manifold.

The Hydraulic Actuator used for this testing, shown in Fig. 4.5, is an MTS model 242.09 actuator with ±2 inches (±5 cm) of stroke. The actuator has a force capacity of

2200 lb (10 kN), which is adequate for testing the seat suspension. The actuator is equipped with an internal load cell and linear-variable differential transformer (LVDT) for measuring actuator force and displacement, respectively. Two MTS model 249 Swivel ends are mounted to the actuator to correct for any misalignment between the actuator and upper and lower plates.

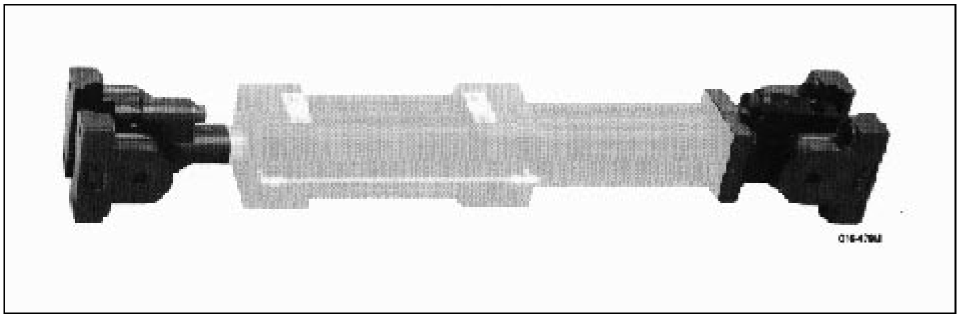

Figure 4.5. MTS 242 Series Hydraulic Actuator.

The hydraulic system is controlled by an MTS model 407 Controller, shown in Fig. 4.6. This controller is a single-channel, digitally-supervised, servo controller that provides complete control of the servo-hydraulic actuator. The controller can be used to prescribe a given displacement or force at the actuator.

Figure 4.6. MTS 407 Controller.

4.3 Seat Base Excitations

Two basic excitations were used to excite the base of the seat suspension for this research. The first type of excitation is simply a pure tone sine (single frequency) excitation. The pure tone excitation was directly generated using the MTS 407 Controller. The second type of excitation is the International Standards Organization (ISO) class 2 (ISO2) excitation [34]. The power spectral density (PSD) of the ISO2 input is shown in Fig. 4.7, and a sample time trace is shown in Fig 4.8. The ISO2 excitation is a relatively broad-band excitation, with frequency content from approximately 1 to 4 Hz, that ISO uses for earth-moving machinery vehicles. The ISO2 excitation was selected for use in this research since it is commonly used by the Original Equipment Manufacturers (OEM) and seat manufacturers for evaluating seat suspensions. The ISO2 excitation is generated externally using a 133-MHz Pentium Gateway 2000 computer and a National Instruments data acquisition card, which will be described later.

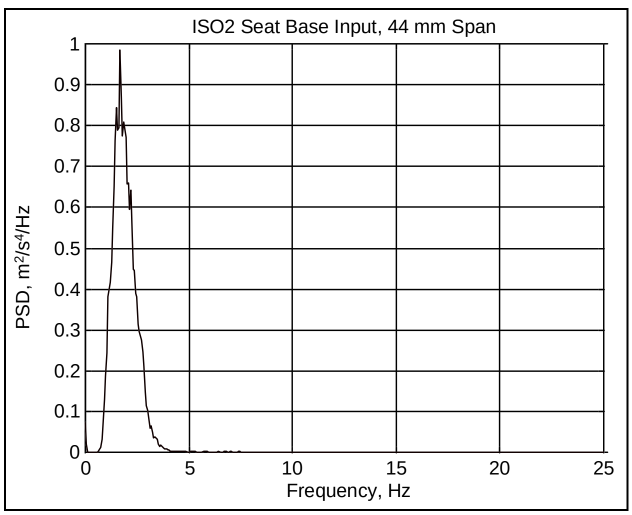

Figure 4.7. ISO Class 2 Excitation.

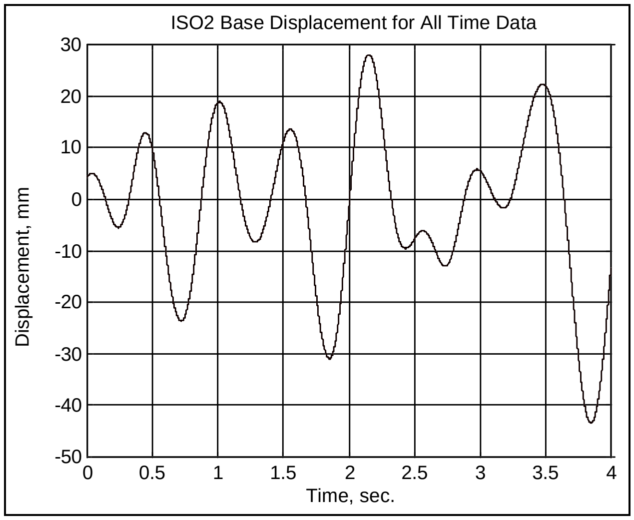

Figure 4.8. ISO2 Base Displacement Sample.

4.4 Data Acquisition Equipment

This section describes all of the laboratory equipment used for data acquisition for this research.

4.4.1 Hewlett Packard Dynamic Signal Analyzer

The main piece of test equipment used for this research is the Hewlett Packard 35665A Dynamic Signal Analyzer (HP Analyzer) shown in Fig. 4.9. The HP Analyzer is a two-channel FFT spectrum/network analyzer with a frequency range from near DC to just over 100 kHz. The HP Analyzer has built-in anti-aliasing filters and user-selectable frequency ranges and resolutions. The HP Analyzer is capable of measuring linear spectrums, auto power spectrums, cross spectrums, frequency response functions, and coherence.

Figure 4.9. HP 35665A Dynamic Signal Analyzer.

The HP Analyzer was used to collect all of the frequency domain data for this research. The Analyzer was set to a frequency range of DC to 25 Hz with 400 lines of resolution. This results in a 1/16th of a Hertz frequency resolution in the frequency domain. A Hanning window was also applied to prevent spectral leakage.

4.4.2 PCB Accelerometers and Signal Conditioner

The seat base and suspended seat accelerations were measured using PCB model 333A accelerometers and a PCB 584 signal conditioner. Figure 4.10 shows the positions in which the accelerometers were hot-glued to the seat base and the cushion support.

The 333A accelerometers are capable of measuring frequencies from 1 to 1000 Hz with a 100 mV/g sensitivity. The acceleration range of the accelerometers is ±50 g peak. The Series 584 Signal Conditioner provides user-selectable gains of 1, 10, and 100 so that both small and large signals can be measured.

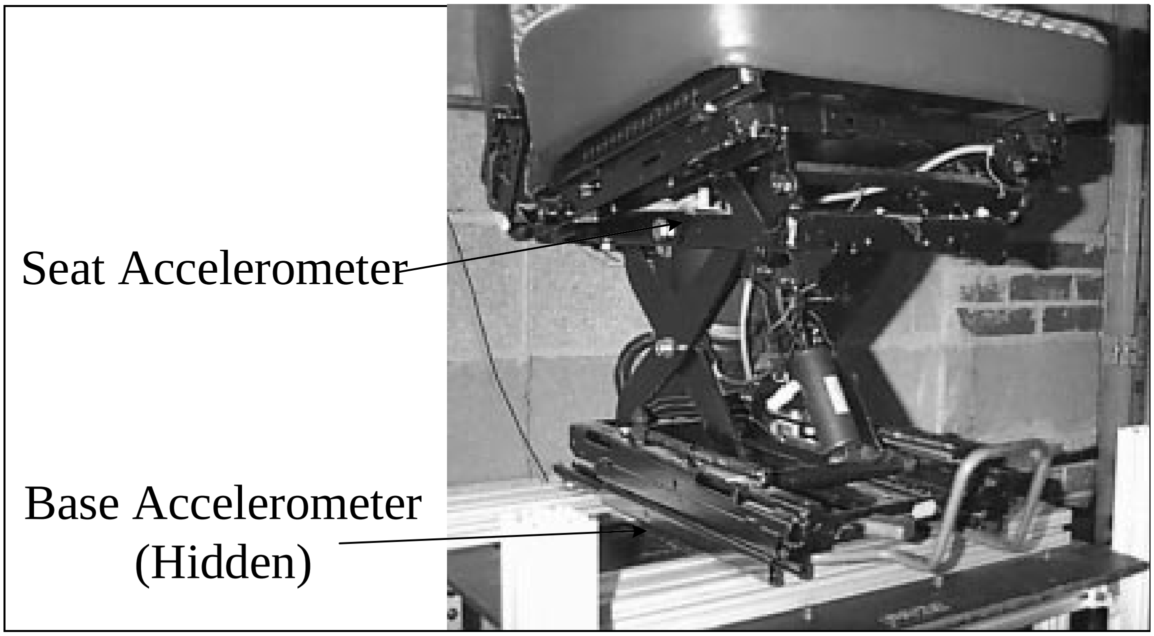

Figure 4.10. Accelerometer Positions.

4.4.3 National Instruments Data Acquisition Card

The purpose of the National Instruments AT-MIO-16E-10 Data Acquisition (DAQ) card is two-fold. First, the DAQ card provided the ISO2 excitation signal for the MTS 407 controller, and secondly, it was used to collect the time domain data.

The AT-MIO-16E-10 DAQ card has 16 analog input and 2 analog output channels built in. It can sample 16 analog inputs at a rate of about 6000 samples per second. The analog inputs have a 12-bit analog-to-digital (A/D) converter resolution, with a user-selectable gain of 0.5, 1, 2, 5, 10, 20, 50, and 100. The analog output has an update rate of 50 kHz for two channels, with a 12-bit resolution in the digital-to-analog (D/A) converter. Whenever the analog inputs or outputs are used, a Frequency Devices model 9002 Analog Filter, shown in Fig. 4.11, is used as an anti-aliasing or reconstruction filter. The Frequency Devices filters have user-selectable cut-off frequencies and signal gains.

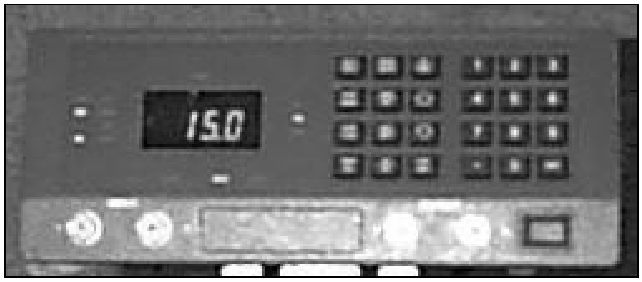

Figure 4.11. Frequency Devices Analog Filter.

The DAQ card is installed in a Gateway 2000 Pentium 133 MHz computer, shown in Fig. 4.12, with LabVIEW software. LabVIEW allows for programming of the DAQ card for data collection, analog signal output, and other applications.

Figure 4.12. Pentium Computer Used for Data Acquisition.

4.4.4 Tektronix Current Probe

In order to accurately measure the current that the controller supplies to the damper, a Tektronix model A622 Current Probe was used, as shown in Fig. 4.13. The A622 measures current ranging in frequency from DC to 100 kHz. The sensitivity can be selected from 10 or 100 mV/A, and can be increased by looping the conductor more than once through the probe. The probe can measure up to 100 Amps peak.

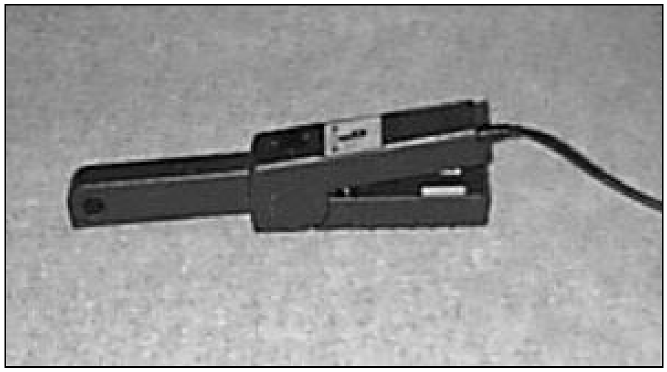

Figure 4.13. Tektronix A622 Current Probe.

4.5 Lord Seat Tester

The Lord seat tester, shown in Fig. 4.14, is very similar to the Virginia Tech seat test system. The actuator is a 6000 lb (26700 N) Lansmont model 6000-40 hydraulic actuator powered by a 75 GPM (278 ℓ/min) pump and a 40 GPM (148 ℓ/min) servovalve. The actuator has ±3 inches (7.62 cm) of stroke. The hydraulic fluid is supplied to the actuator at 3000 psi (29 MPa). The actuator is directly bolted to a seismic mass of concrete set into the floor of the laboratory. The seat is then mounted to the actuator using a small plate of aluminum and extruded aluminum from 80/20 (not shown in photo). The actuator is controlled using an MTS 406 controller, allowing for the same types of excitations as the Virginia Tech tester.

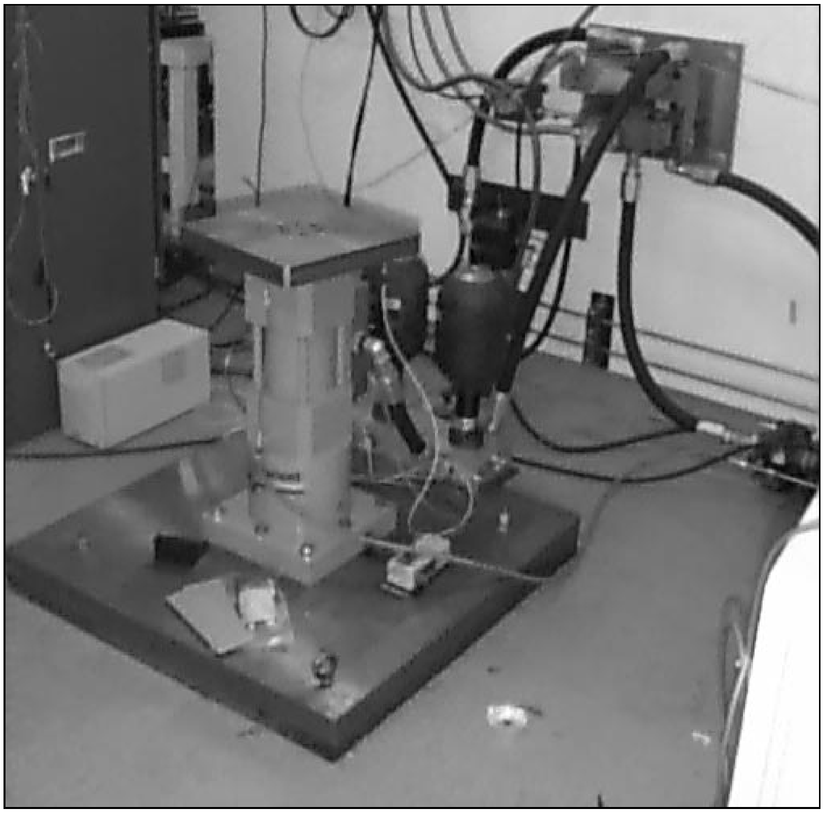

Figure 4.14. Lord Seat Test Actuator.

The Lord test facility also includes a dSPACE model 1102 digital signal processor (DSP) controller board. The 1102 DSP board is mounted in a PC which is installed with MATLAB and SIMULINK. The 1102 has two 16-bit and two 12-bit analog inputs, and four 12-bit analog outputs. The 1102 DSP board is then directly interfaced with MATLAB and SIMULINK, which allows for rapid prototyping of different control policies through SIMULINK.

A hardware interface has been set up between the dSPACE board and the seat suspension that duplicates the hardware interface of the Lord controller (Chapter 3). This allows for the duplication of the Lord controller using the dSPACE system and the creation of new control policies that use the existing hardware interface.

The Lord test facility also includes an HP 35670A Four-channel Dynamic Signal Analyzer, which is similar to the HP Analyzer at Virginia Tech. The Lord HP Analyzer also includes the Swept Sine Option, which allows the analyzer to measure the frequency response of a system using a swept sine excitation.

4.6 Frequency Data Analysis

An HP Analyzer can be set up such that it can compute the auto spectrum, linear spectrum, or frequency response functions of the signal that is measured. This section will describe the measurement used for data analysis in the frequency domain.

The average auto spectrum (also known as the auto power spectrum) of a collection of frequency spectra, $X_k(\omega)$, is defined as

$$G_{xx}(\omega) = \frac{2}{M}\sum_{k=1}^{M} X_k(\omega) X_k^*(\omega) \tag{4.1}$$

where $X_k^*(\omega)$ indicates the complex conjugate of $X_k(\omega)$. The constant M denotes the number of averages, and the factor of 2 is used for a single-sided auto spectrum. The auto spectrum is a real number and thus only provides information about the magnitude of the frequency spectrum. Normalizing the auto spectrum to a 1-Hz frequency bandwidth yields the power spectral density (PSD), which is a good indication of the energy across the frequency spectrum.

The Lord HP Analyzer can also be set up so that it can find the swept sine frequency response of a dynamic system. The swept sine method essentially entails exciting the structure using a pure tone excitation and measuring the steady-state response of the structure once the transient response has died out. This method is effective for characterizing non-linear systems with a high signal-to-noise ratio. The main disadvantage to the swept sine method is the large amount of time that is required to find the frequency response of a system.

One must be very careful when interpreting the swept sine results. Even though a constant acceleration of 2 m/s^2 was used over the entire frequency range tested, the system contains non-linear elements. Thus, all assumptions that are made for linear systems are not necessarily true (i.e., doubling the input results in doubling the output).