

Chapter 3

Experimental Setup

This chapter describes the experimental setup of the test stand used for laboratory testing at the Advanced Vehicle Dynamics Lab (AVDL) of Virginia Tech. First, the structural design of the test stand will be discussed. Next, the test setup will be described including the input excitation and data acquisition systems. Tests that validate the frequency range, linearity, and repeatability of the test stand will also be presented.

3.1 Test Stand Design

The test stand was designed and fabricated for testing and evaluating the effectiveness of piezoelectric damping materials for reducing both vibrations and structure-borne noise. The test stand enables vibration and acoustic measurements and analysis on a steel plate with clamped-clamped boundary conditions. The plate, simulating an automotive structure, is clamped rigidly around its edges and excited over a frequency range of 50-450 Hz. Various standard flooring materials, such as carpeting, passive damping materials, and smart damping materials, are added to the panel in order to evaluate their effect on reducing the plate vibrations and subsequent noise.

The test stand, shown in Figure 3.1, includes a bottom enclosure, top enclosure, excitation frame, and electromechanical shaker. Measurements are taken with two accelerometers, located on the plate and excitation frame, and a microphone positioned in the upper reception chamber. The reception chamber and bottom enclosure are designed to eliminate background noise and isolate the noise generated by the electromagnetic shaker and the plate.

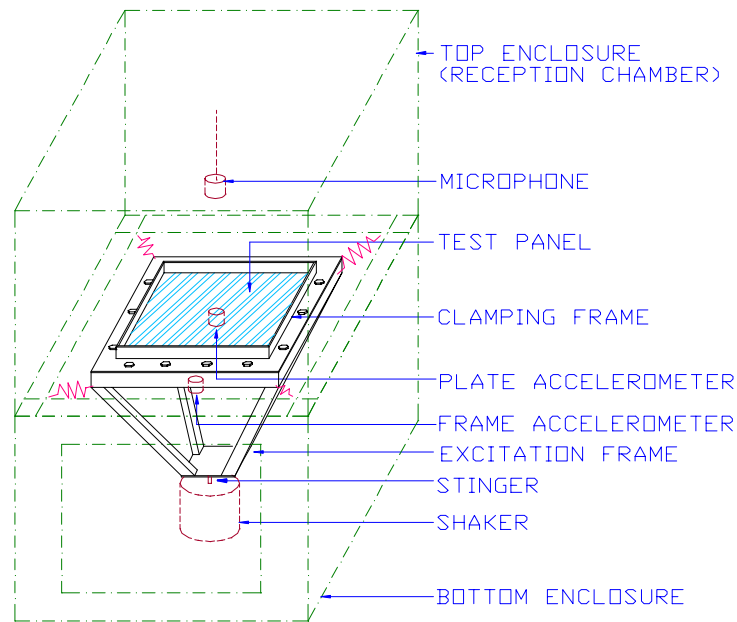


Figure 3.1. Vibration and Acoustics Test Stand Schematics

The first part of the test stand is a four-sided box that rests on the ground and encloses the shaker and excitation frame, as shown in Figure 3.1. The excitation frame attaches to the shaker with a stinger rod, and hangs from the box by four springs. The test plate rests on top of the excitation frame and is bolted in place by a clamping frame structure resembling a picture frame. Another component of the test rig is the top enclosure, a five-sided box that rests on top of the bottom box. A microphone hangs from the top of this enclosure, at a distance of 500 mm above the center of the test plate. The microphone is used to measure the noise emitted by the test plate during frame excitation. The following sections describe the design details of various components of the test stand.

3.1.1 Bottom Box Enclosure

The bottom box framework, illustrated in Figure 3.2, is constructed from high strength extruded aluminum beams manufactured by 80/20 Inc. The aluminum beams have extruded T-shaped profiles that allow nuts to be captured, thus facilitating easy joining and bracing of the structure. As shown, the box frame is supported at the corners by aluminum gussets which are also manufactured by 80/20 Inc. The bottom box width and depth were designed to fit the excitation frame dimensions. The height was designed so

that the box could accommodate the shaker, the stinger, and the excitation frame. This yielded a box 38 in high, 40 in wide, and 36 in deep. The excitation frame hangs from the bottom box framework.

The back, left, and right sides of the box are made from 20-gauge steel sheet. The inside faces are covered with viscoelastic barrier material to help isolate the structure from vibrations, and to act as a gasket between the 20-gauge sheet and the aluminum beams.

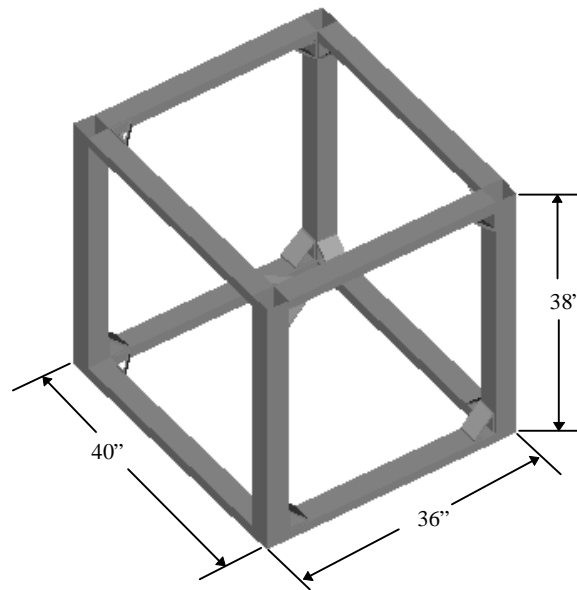


Figure 3.2. Frame for Bottom Box Enclosure

The inside of the enclosure is lined with acoustical foam to absorb the acoustical energy emitted by the bottom of the test plate, minimizing any reflected sounds. This is necessary because the sound level measured by the microphone must come from one source, the test plate. The acoustical foam is attached to Styrofoam frames that are glued to the inside of the steel sheets. These Styrofoam frames allow air between the acoustical foam and the steel sheet, providing further acoustical insulation. Figure 3.3 shows a sectional view of one side of the bottom enclosure, looking down from the top. The front side of the enclosure is similar to the other sides, except that it is made from 1/8-inch-thick steel sheet because it must accommodate the front door.

To isolate the enclosure from vibrations transmitted through the floor by the shaker, closed-cell foam is placed between the bottom of the bottom box and the floor.

Closed-cell foam is also placed on the top/bottom box interface so that the top box rests on the closed-cell foam and not directly on the bottom box. This helps to better acoustically seal the top and bottom boxes.

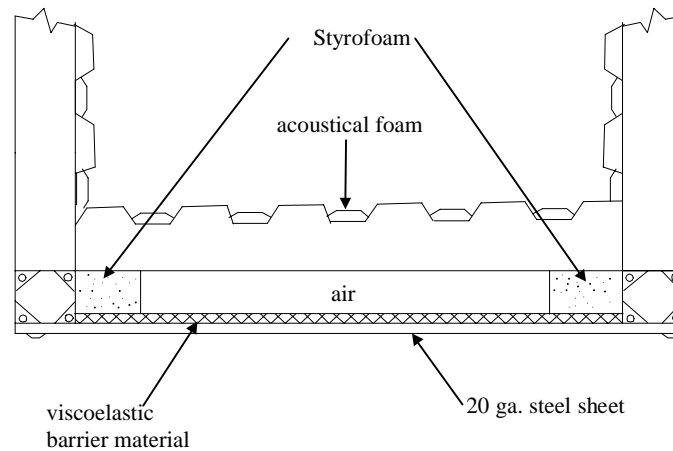


Figure 3.3. Section View of Bottom Box Enclosure Side

A 26 in x 26 in 20 gauge steel door, shown in Figure 3.4, seals a 2 ft x 2 ft opening in the bottom enclosure that allows access to the shaker and excitation frame. Magnetic gasket material, similar to a refrigerator door, was attached to a two-inch overhang on the door in order to seal the door acoustically. Viscoelastic barrier material, Styrofoam, and acoustic foam were applied to the door in the same manner as to the other sides of the box. The door has two handles and is supported by two hexagonal bolts attached to the 1/8-in sheet below the door.

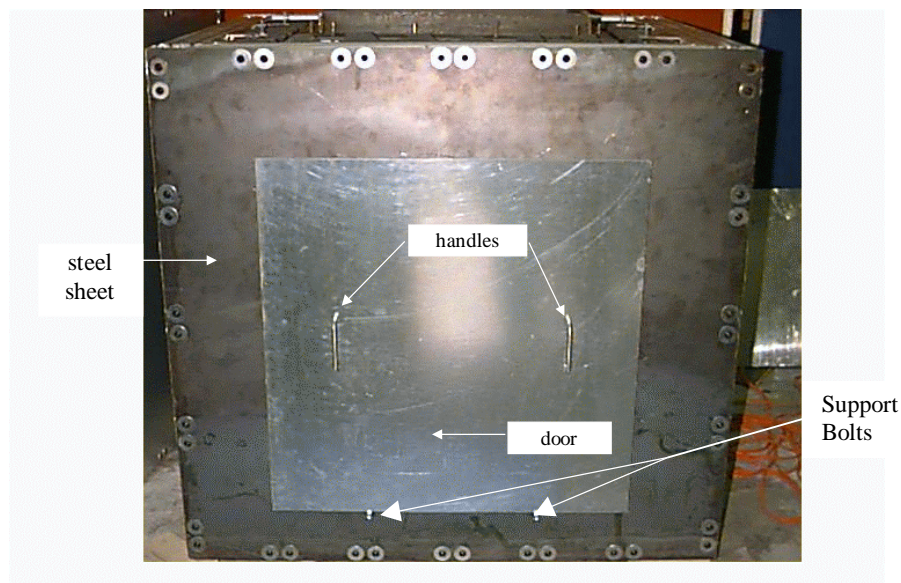


Figure 3.4. Front Side of Bottom Box Enclosure with Door

3.1.2. Top Box Enclosure

The top box was designed to be similar to the bottom box, incorporating the extruded aluminum beams and 20-gauge steel sheets for the top, front, back, right, and left sides. The sides were bolted to the beams and had damping and acoustical foam installed in the same manner as in the bottom box. The overall dimensions of the top box are 40 in high, 40 in wide, and 36 in deep. The top enclosure, however, did not need to support structural loads, so smaller beams were used in the frame. The inside face of the top panel has 8-inch acoustic wedges glued to a foam sheet instead of the acoustical foam. Figure 3.5 shows the inside of the top box, looking up into it towards the top (the 8-in acoustic wedges are white). Four handles are mounted to the top of the reception chamber so that a chain and a hoist can be attached in order to raise and lower the enclosure.



Figure 3.5. Inside of Reception Chamber

3.1.3. Excitation Frame

The excitation frame, shown in Figure 3.6, is an inverted trapezoidal pyramid that is 50 cm in height and has bases that are 15 cm x 15 cm and 50 cm x 60 cm in dimension. The frame was designed so that none of its flexural modes would occur in the range of

frequencies to be measured. If a natural frequency of the frame would occur between 50 and 450 Hz, then it would distort the excitation energy from the shaker to the test plate. This in turn distorts the output data, resulting in poor coherence measurements between the input and output signals.

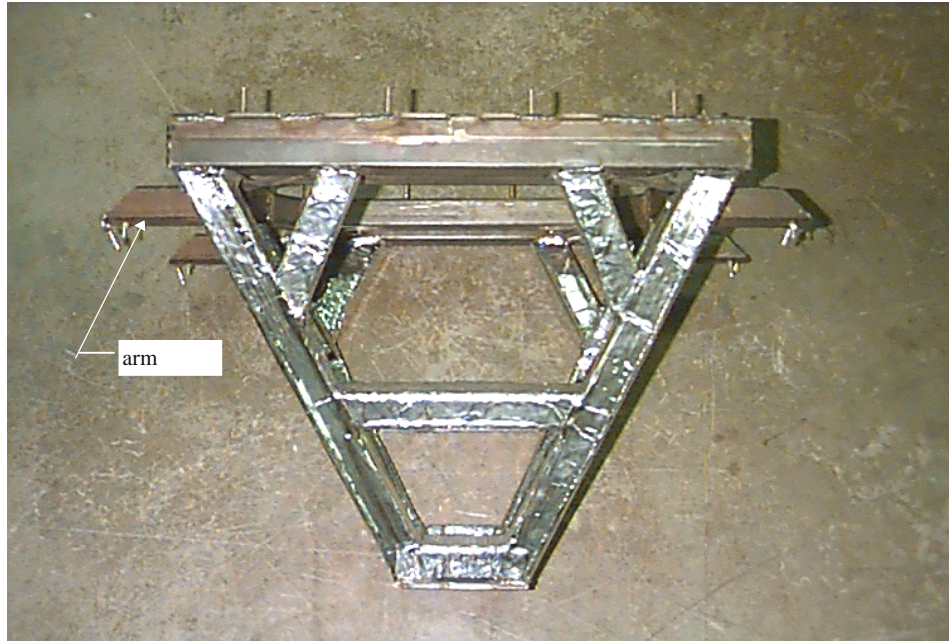


Figure 3.6. Excitation Frame

Four horizontal arms welded to the frame, as shown in Figure 3.6, are used to suspend the excitation frame from the frame's upper beams. As shown in Figure 3.7, each arm has a suspension configuration that is an extension spring with an eyebolt attached at its ends. One eyebolt connects to the frame arm, and the other eyebolt connects to the bracket that mounts to the enclosure frame. The springs allow the excitation frame to oscillate vertically, transmitting the vibrations to the test plate. The springs were designed such that the suspended frame dynamics do not interfere with the test plate dynamics. The rigid body modes of the suspended frame were determined to be below 10 Hz, and therefore below the test frequency range of 50-450 Hz.

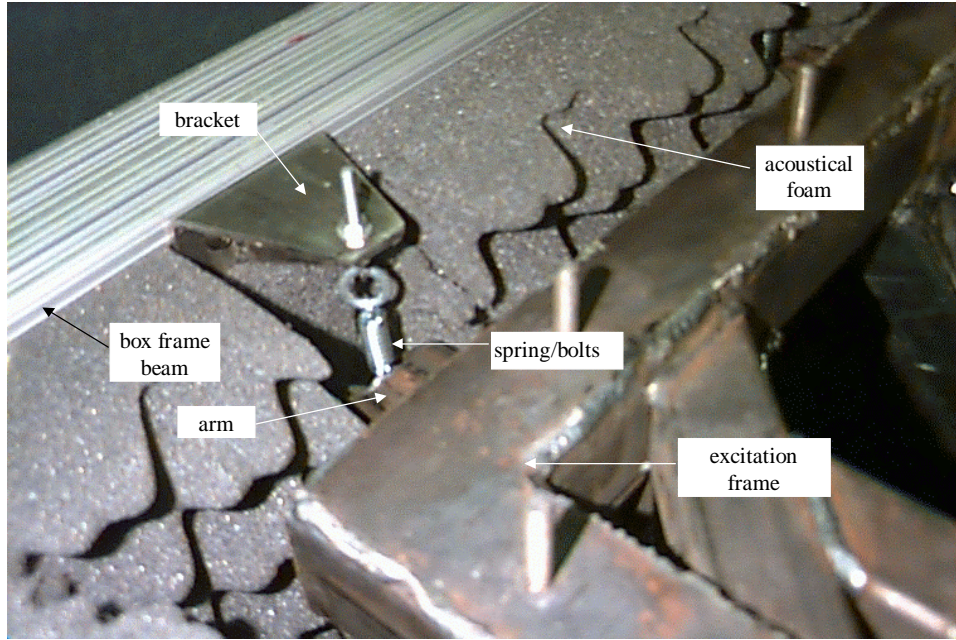


Figure 3.7. Excitation Frame Mount to Bottom Box

The clamping frame is bolted to the excitation frame so that the test plate is clamped securely between the frames, as shown in Figure 3.8. The frame was fabricated from 2-in steel angle iron steel with a 1/8-in thickness. The outside dimensions of the frame are the same as the test plate, which is 600mm x 500mm. The inside dimensions of the frame are 500mm x 400mm.

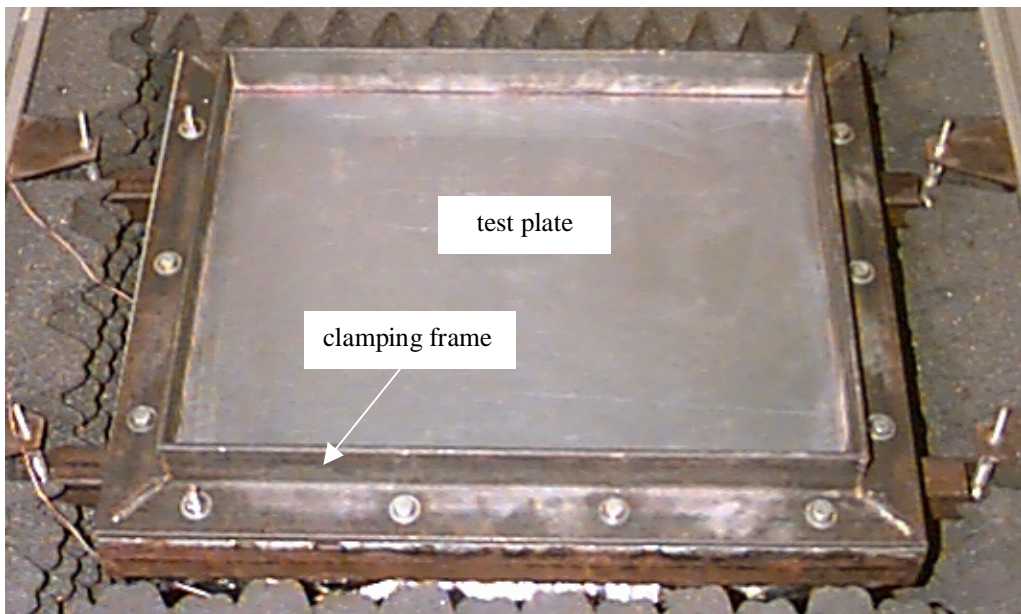


Figure 3.8. Clamping Frame on Excitation Frame

3.1.4 Electromagnetic Shaker

The electromagnetic shaker, shown in Figure 3.9, is a VTS g100-6 100-lb shaker that is bolted to a heavy steel stand that rests on the floor. An amplifier located outside of the enclosure powers the shaker. A stinger rod screws into the top of the shaker at one end and is bolted to the bottom of the excitation frame at the other end.

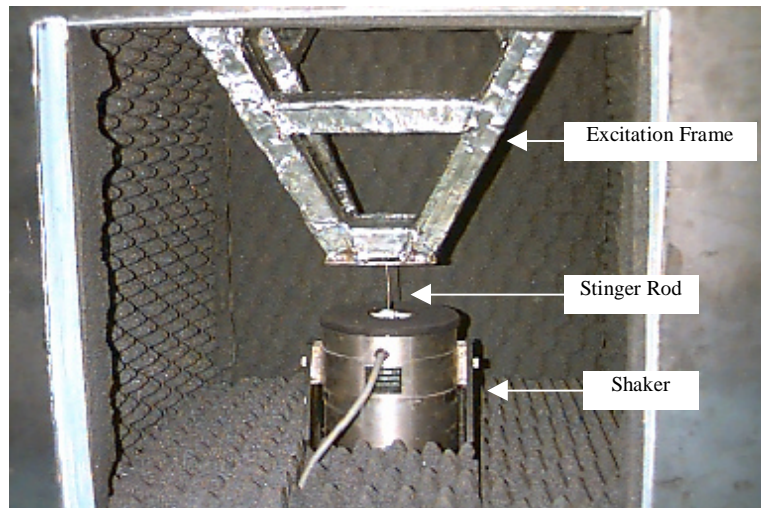


Figure 3.9. Electromagnetic Shaker and Stinger Rod Assembly

3.1.5 Total Test Stand Assembly

As mentioned in Section 3.1.2, a hoist is used to lift and lower the top enclosure on and off the bottom enclosure. The full test stand assembly, shown in Figure 3.10, includes a wooden cart, painted white, that was constructed as a stand for the top enclosure. The top enclosure, which rests on this cart, can be wheeled away from the bottom enclosure in order to access the excitation frame. To lower the enclosure for testing, the cart is wheeled over the bottom and the chain is hooked into the hoist located above the stand. The top enclosure is lifted off the cart, the cart is wheeled out of the way, and the top enclosure is then lowered onto the bottom enclosure.

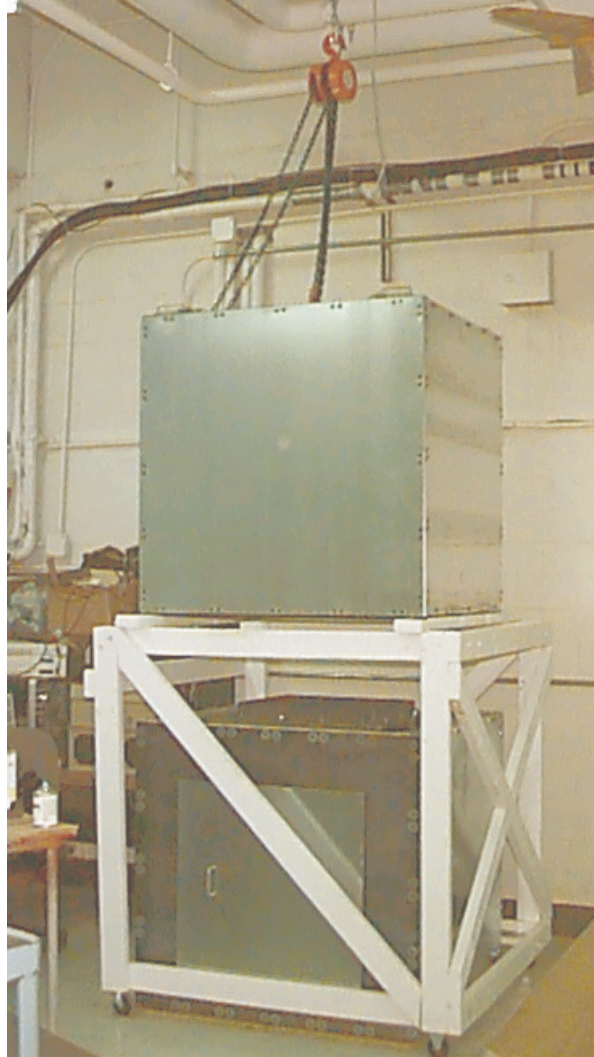


Figure 3.10. Total Test Stand Assembly

3.2 Test Setup

This section outlines the test plate set up, the transducer arrangement, and the data acquisition system used for the structure-borne vibration and noise testing.

3.2.1 Test Plate Setup

For testing, a standard test plate was clamped into place with 14 bolts tightened to a torque of 25 N-m. The standard plate was a 500mm X 600mm, 20-gauge, galvanized steel plate. The plate was bolted as in Figure 3.11 such that the outside 10 cm along the edges were clamped and the remaining test plate area was 400mm X 500mm. The bolts

were always tightened in the same criss-crossing pattern, similar to that for lug nuts on a car wheel, to improve the repeatability of the boundary conditions for the plate.

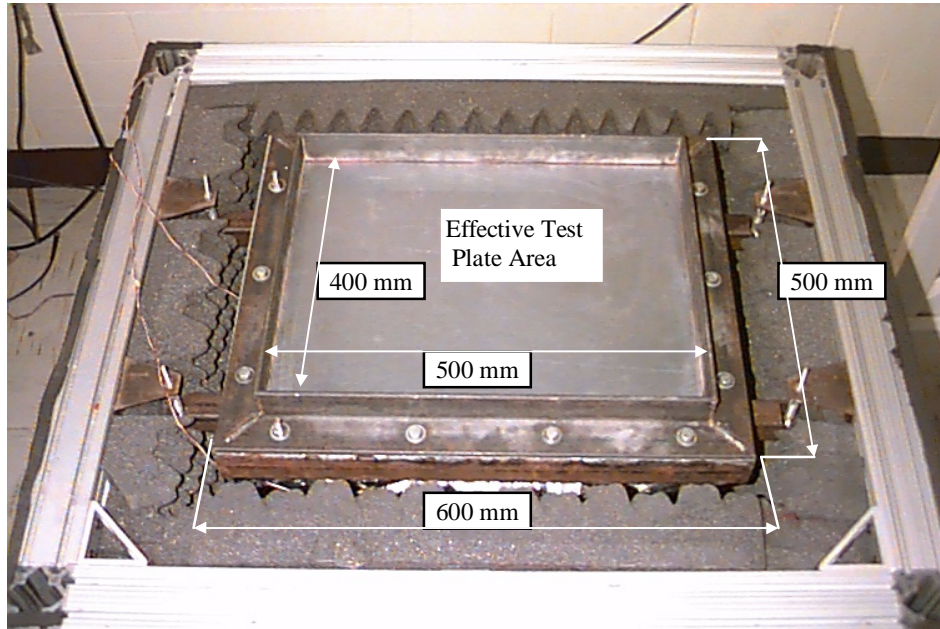


Figure 3.11 Standard Test Plate in Testing Position

An acoustic barrier was then placed over the top of the frame and bottom enclosure, illustrated in Figure 3.12, so that only the test plate area was exposed to the reception chamber.

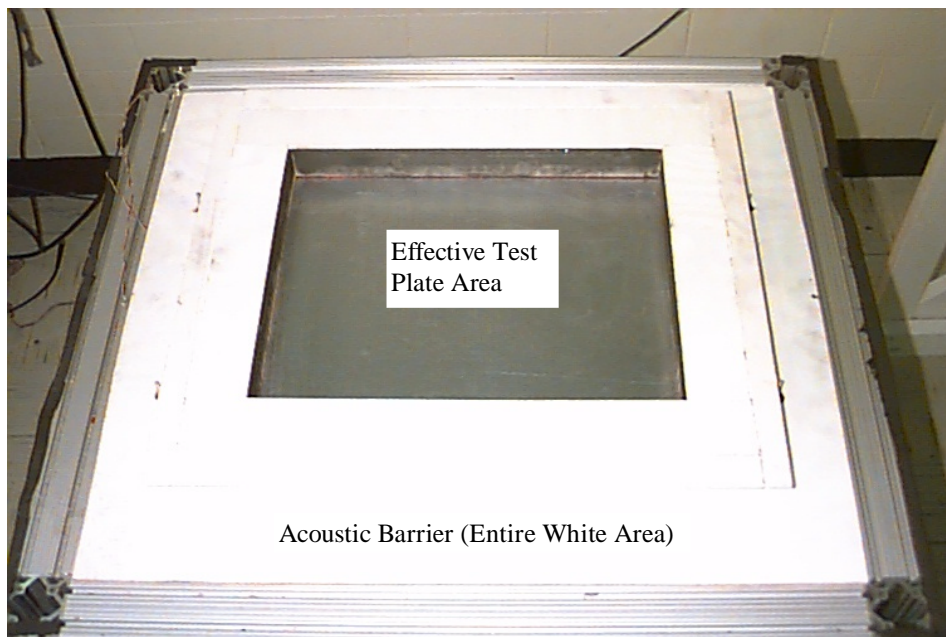


Figure 3.12. Acoustic Barrier Arrangement

3.2.2 Transducer Arrangement

Accelerometers and a microphone were used to measure the frame acceleration, the plate acceleration, and the structure-borne noise. Two PCB Model 33A accelerometers were used to measure the input acceleration of the excitation frame and the plate response acceleration, as shown in Figure 3.1. For the excitation frame, an accelerometer was attached underneath the center of the front top beam. The frame acceleration, assumed to be only in the vertical direction, measures the input for the plate vibration and structure-borne noise. The other accelerometer was attached underneath the center of the test plate to measure the vibration response of the plate. A B&K ½-in microphone (Falcon Range Type BP 1422) was positioned, as shown in Figure 3.13, in the reception chamber such that it was 0.5 m above the center of the test plate during testing. The microphone was secured to a ½-in threaded steel rod that bolts to the top of the reception chamber.

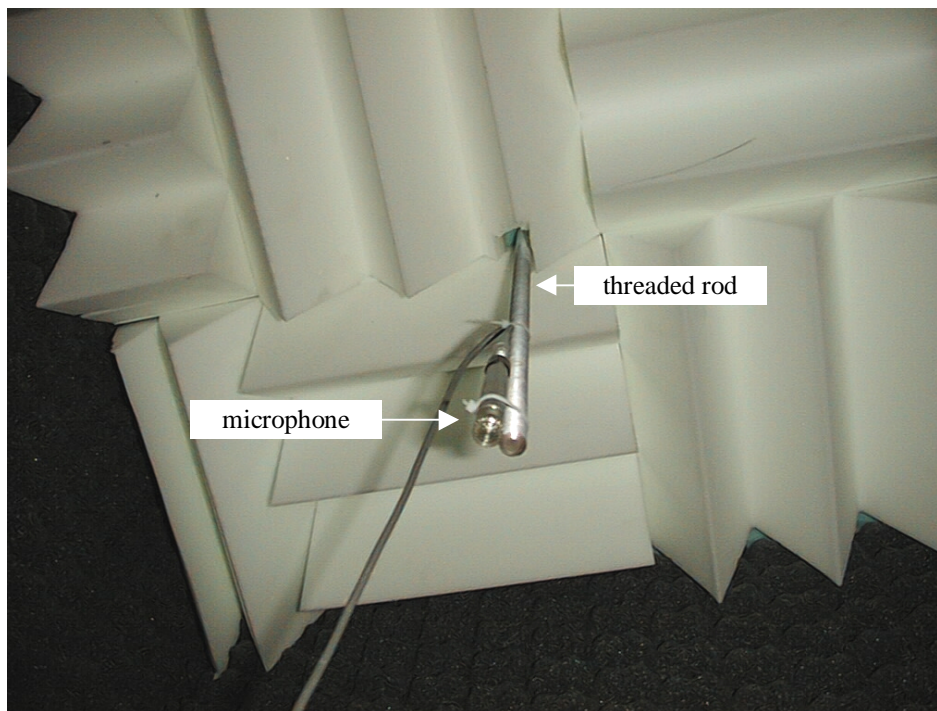


Figure 3.13. Microphone Placement in the Reception Chamber

3.2.3 Data Acquisition System

The data acquisition was set up according to the test schematic shown in Figure 3.14. The Hewlett Packard dynamic signal analyzer served as the data recorder, the fast Fourier transformer, the band pass filter, and the signal generator for controlling the shaker.

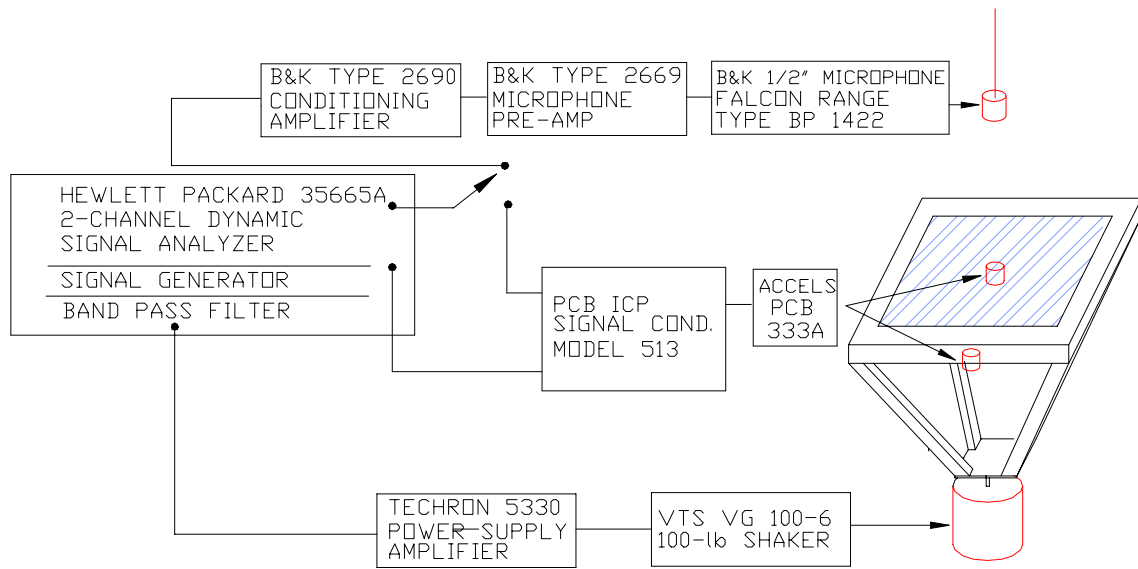


Figure 3.14. Shaker Table Test Stand and Data Acquisition Schematic

Initial tests and experiments were performed with a number of different excitation functions and sampling techniques. A final sampling technique was chosen such that coherence was the highest between the plate acceleration and frame acceleration, and test chamber acoustics (microphone output) and frame acceleration. Coherence is derived from the cross correlation between the input and output measurements. This sampling technique uses the following:

- periodic chirp input signal,
- uniform sampling window (0% overlap),
- source triggering,
- anti-aliasing filter,
- 800 spectral lines, and
- 20 averages.

A periodic chirp input signal, shown in Figure 3.15, was chosen because it had a uniform distribution of energy across the frequency range.

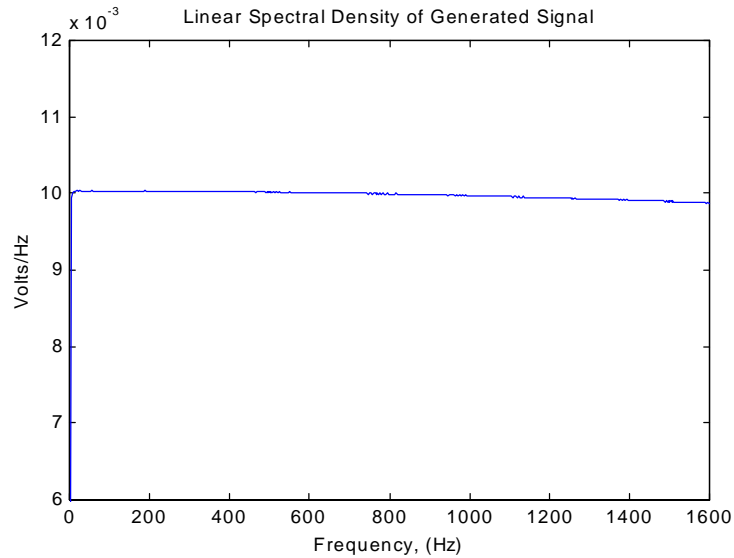


Figure 3.15. Periodic Chirp Signal Generated by HP Analyzer

3.3 Validation Tests

The goals of the validation tests were to ensure that there were no frame resonance frequencies below 500 Hz, and that the parasitic noise, any noise emitted other than from the test plate, was minimal. In addition to these goals, the tests were intended to verify dynamic linearity and test repeatability of the test stand. For these tests, the coherence was monitored to further validate the measurements.

3.3.1 Vibration Response Validation

Although the generated input signal is an ideal signal for testing the frequency response for a plate, the direct input excitation for the plate is from the frame, not from the HP analyzer. Therefore, the frame acceleration was chosen as the input signal for the plate and sound pressure measurements. The desired excitation range for the plate is between 50 and 450 Hz; poor data will result if there are any resonant frequencies of the frame within this range. The frequency response of the frame was then analyzed to ensure that this was not the case. Data were first collected for the excitation frame and clamping frame without the plate in place. Figure 3.16 clearly shows that the major frame structural resonant frequencies occur above 500 Hz. The three rigid body modes, bounce,

pitch, and roll, occur between 5 and 10 Hz. The acceleration frequency spectrum of the frame within the 50-450 Hz range is relatively constant as well.

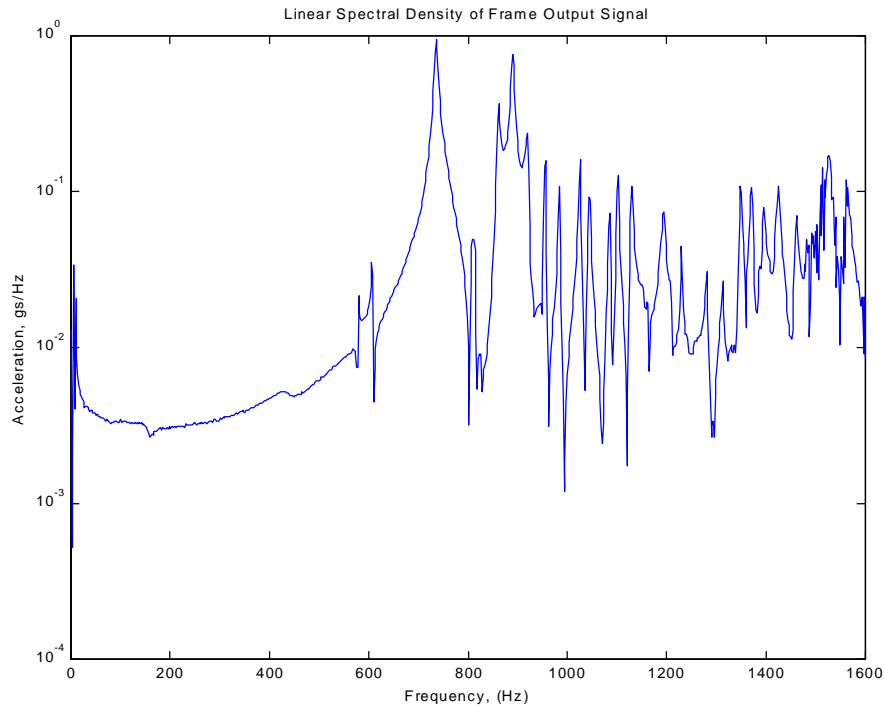


Figure 3.16. Frame Acceleration Response without Test Plate Installed

Figure 3.17 shows the effect of the test plate on the frame response when it is clamped in the frame. For the same amount of input energy to the shaker, the frame acceleration is decreased due to mass loading from the plate. For this reason, the data are always recorded relative to frame acceleration because different damping treatments will have different mass loading effects.

There are also some coupling effects between the frame and plate at the resonant frequencies of the plate. This is another reason for recording data relative to frame acceleration. These resonant peaks are clearly illustrated in the sample data shown in Figure 3.18 for an undamped standard test plate.

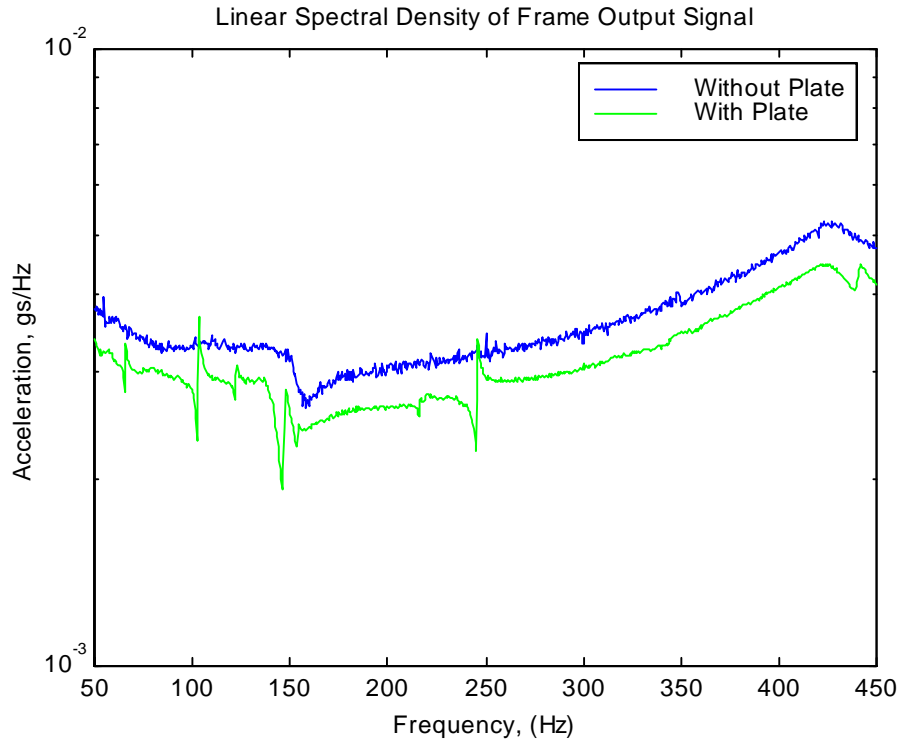


Figure 3.17. Effect of Test Plate on Frame Acceleration Response

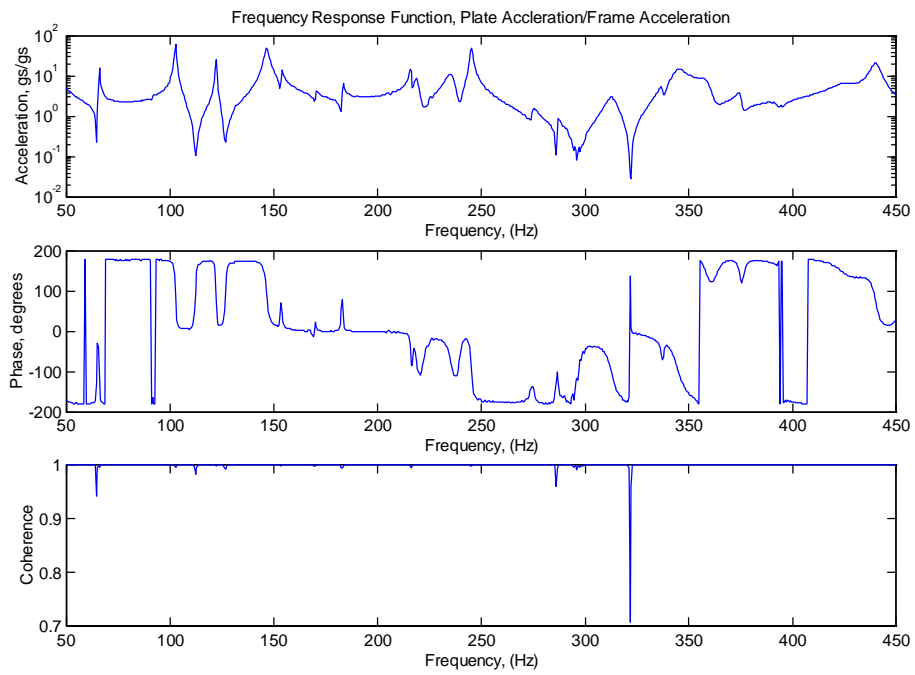


Figure 3.18. Sample Frequency Response Function Data for Standard Test Plate

3.3.2 Acoustic Response Validation

Acoustic validation tests were performed to determine the noise floor as well as to measure how well the acoustic data correspond to the plate vibration data. Acoustic data were also taken without the test plate to determine how much noise the frame and shaker generated. It is clear from the data, shown in Figure 3.19, that the frame and shaker do contribute some amount of additional noise, but the sound levels at the peak resonant frequencies are at least 20 dB above the noise levels. Additionally, when the plate is in place, the plate acts as an additional acoustics barrier. Sample acoustics data in Figure 3.20 show that there is a direct correspondence between plate accelerations and sound pressure levels.

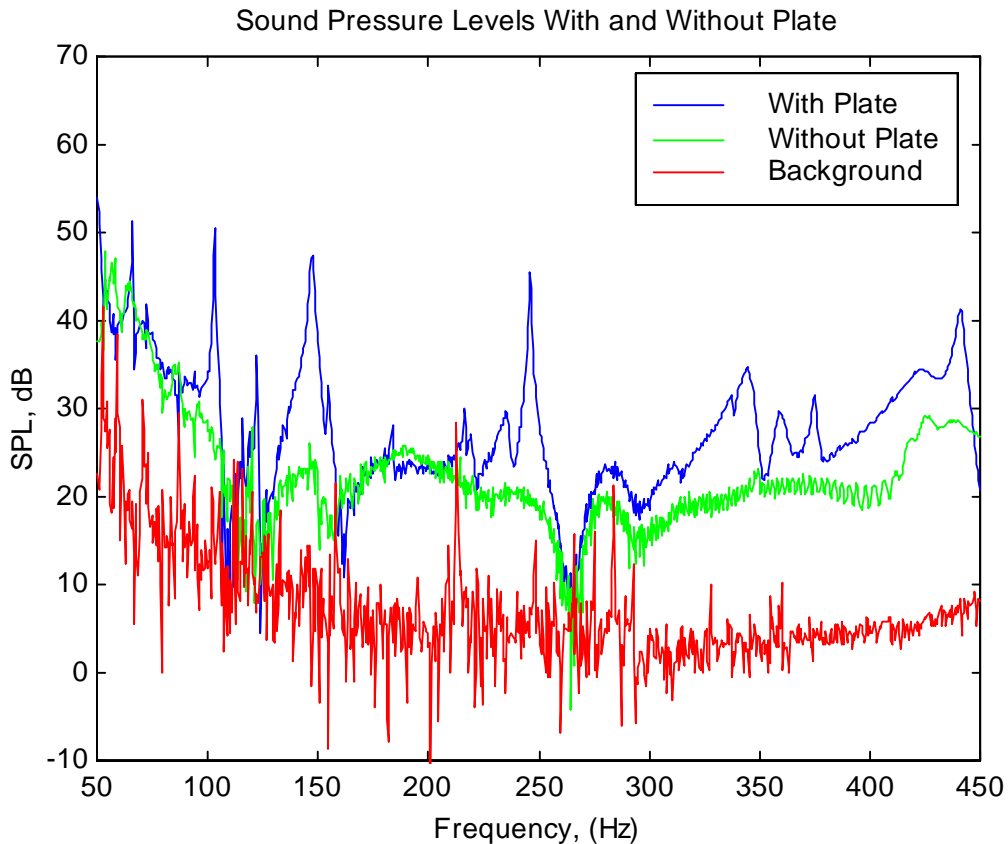


Figure 3.19. Sample Sound Pressure Levels With and Without Plate

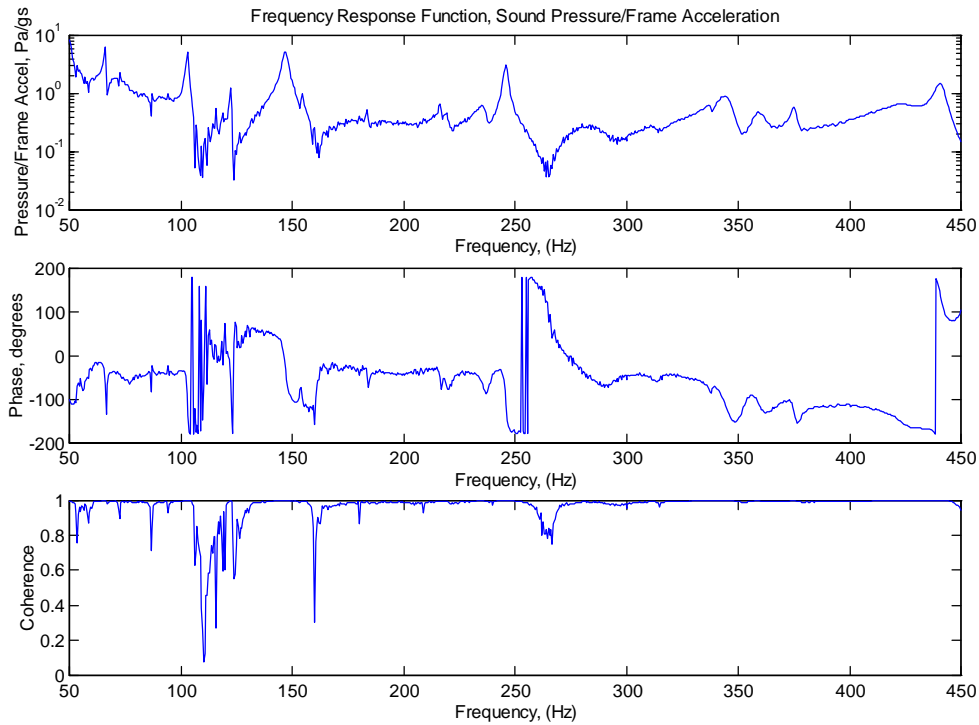


Figure 3.20. Sample Frequency Response Function Data for Standard Test Plate

3.3.3 Repeatability and Linearity

Additional tests were performed to verify the linearity and repeatability of the tests performed on the test stand. Linearity implies that if the frame acceleration is increased by a certain ratio, then the plate acceleration and sound pressure will increase by the same ratio. This effect results in frequency response functions that remain constant regardless of the input level. As Figure 3.21 shows, relatively linear responses were achieved for the sound pressure levels and the test plate accelerations due to the increased input level (frame acceleration) within the 50 to 450 Hz frequency range.

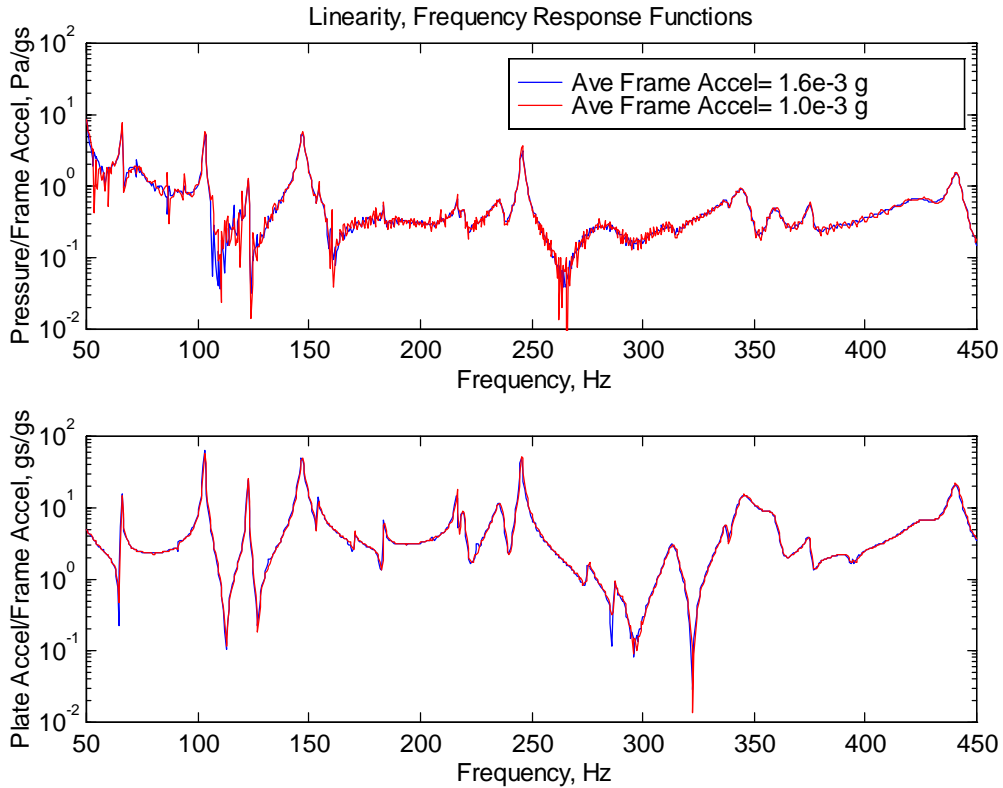


Figure 3.21. Linearity Test Results for Two Levels of Frame Acceleration

Repeatability was also tested to verify that the clamping conditions remained relatively constant from one test to the next, and that the natural frequencies and vibration levels did not differ excessively. As illustrated in Figure 3.22, the test chamber sound pressures and plate accelerations were quite similar for two tests conducted at different times on a standard test plate. After Test 1 was completed, the plate and accelerometers were removed. For Test 2, the plate was remounted in the test stand and the accelerometers were reattached. In this regard, it was determined that as long as the test setup guidelines are followed, as per Section 3.2, the tests were accurately repeatable.

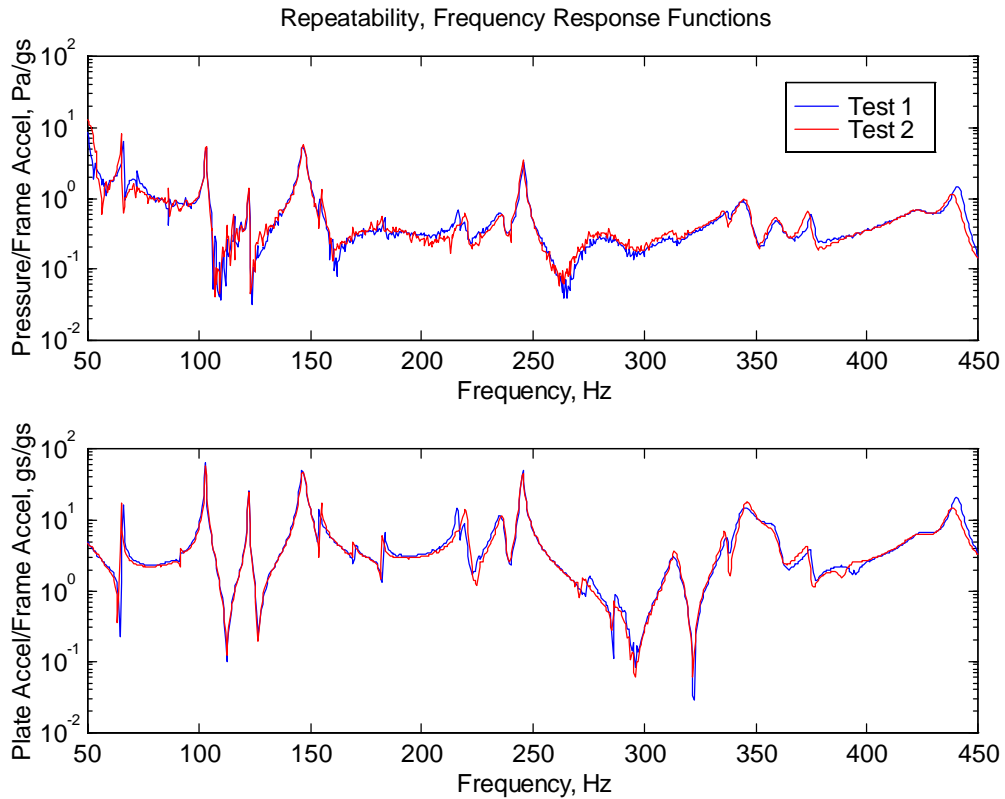


Figure 3.22. Repeatability Test Results for Standard Test Plate

3.4 Summary

The test stand construction, the experimental setup, and the validation tests were discussed in this chapter. The test stand was designed and built to perform structure-borne vibration and noise experiments for the investigation of the application of smart damping. The validation tests established the best excitation and sampling technique, determined that there were no frame resonance frequencies below 500 Hz, and determined that the parasitic noise was minimal. In addition, the validation tests verified the dynamic linearity and test repeatability of the test stand.