Chapter 4

Baseline Testing and Validation

The locomotive cab used in this study was tested in a soft-mounted and hard-mounted configuration. The cab was separated from the sills by six off-the-shelf elastomeric mounts from Lord Corporation (Erie, PA) as described in Chapter 3. To return the cab to its original baseline configuration, rigid steel plates, with very large static stiffness, were used in place of the rubber mounts. This chapter describes the tests that were performed on the cab to establish the excitation input to the cab and the test validity.

4.1 Baseline Cab Configuration

The baseline is defined as the configuration in which the locomotive cab is hard-mounted to the sill structure that supports the cab and other locomotive components. The cab and sill structure are shown in Fig. 4.1.

(a)

(b)

Figure 4.1 The Locomotive (a) Cab (b) Sill Structure

This original configuration of the cab was modified shortly after it was received at Virginia Tech. In order to conduct a study in vibration modeling and experimentation, the cab was soft-mounted to the sill structure vertically at its four corners using four elastomeric mounts, (Fig. 4.2), as well as at the crash-posts using two more mounts, (Fig. 4.3). The soft-mounting was accomplished by separating the welds between the cab, the sill structure, and the four needle beams that are connected to the sill. For the baseline testing in the study, the cab was nearly returned to its original configuration by using steel plates in place of the soft mounts as shown in Fig. 4.4. The crash post mounts were not changed, since their contribution to vertical vibration, which is the main focus of this study, is minimal.

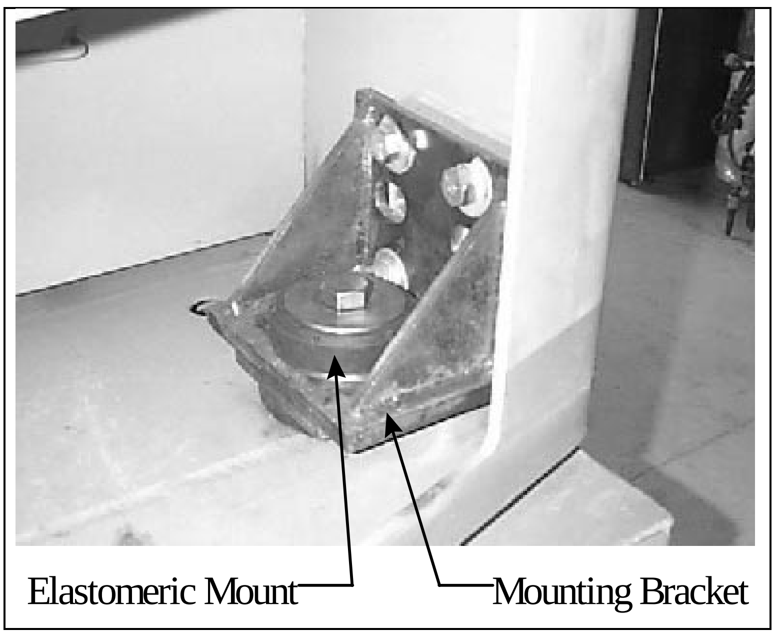


Figure 4.2 B-Side Front Soft Mounting

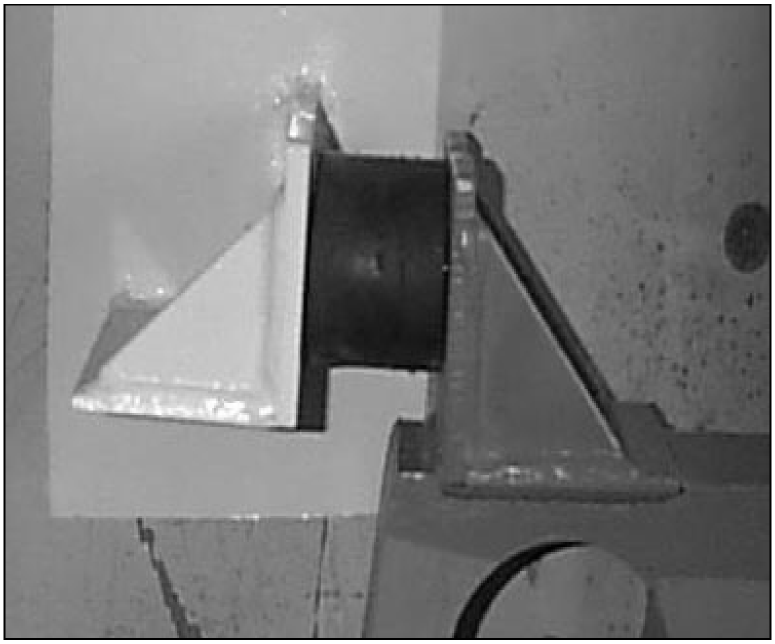


Figure 4.3 Crash Post Mount

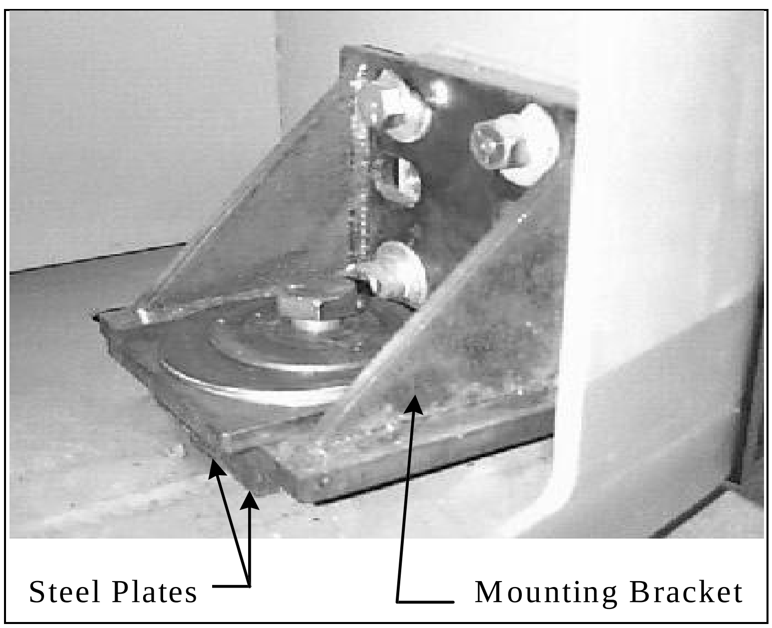


Figure 4.4 B-Side Front Hard Mounting

Other alterations to the cab that affected the original cab configuration were the addition of new beams under the cab floor. As shown in Fig. 4.5, the floor was welded to the new beams and existing floor beams in order to stiffen it and reduce vibrations. Further details of this modification can be found in [14]. For the purpose of this study, the floor was maintained in its stiffened configuration since it did not interfere with the main goal of our research.

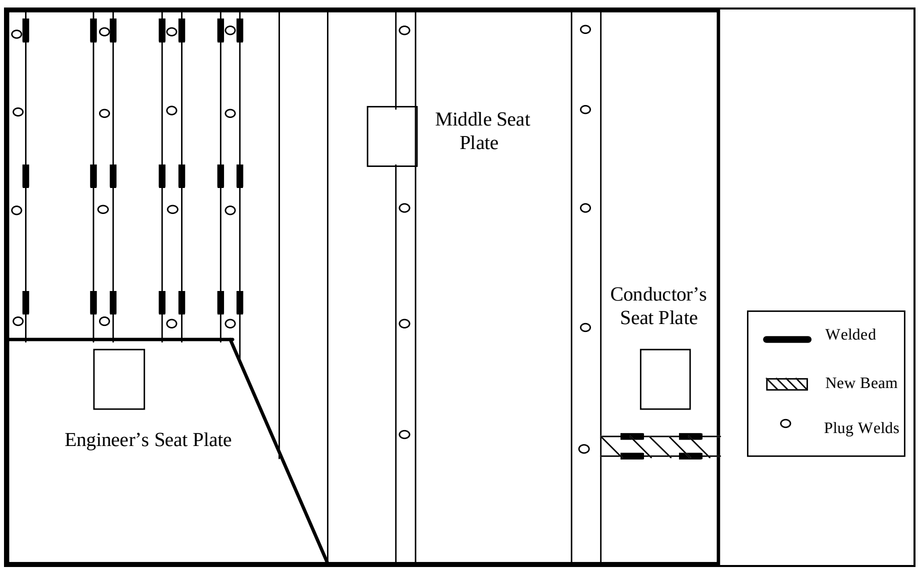


Figure 4.5 Modifications for Stiffening the Cab Floor

4.2 Baseline Test Input

The main two issues in establishing the baseline input were selecting a location for effectively exciting the cab, and duplicating cab vibration input from the field.

The location for exciting the cab was determined by evaluating how well the cab responded to a random vibration input from the hydraulic actuator. In an earlier study, it was shown that the aft B-side attachment is the most efficient location for exciting the cab [14]. As shown in Fig. 4.6, at this location, the hydraulic actuator is connected to the sill structure near a short needle beam with a very high bending stiffness.

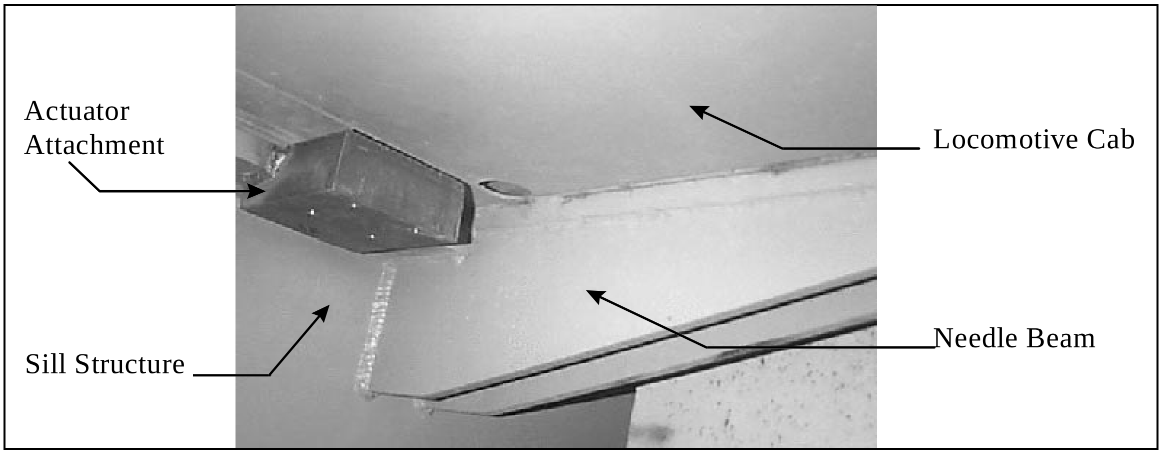


Figure 4.6 Hard-Mounted Cab/Sill Interface

The field data that was used to generate the input was collected at the B-side aft attachment point on the cab, as shown in Fig. 4.7, while the diesel engine on the locomotive was operating at 4375 horsepower. The coordinates for the field accelerometer were determined to be 31.125 in. in the x direction, 46.75 in. in the y direction, and -4.25 in. in the z direction with respect to the global coordinates.

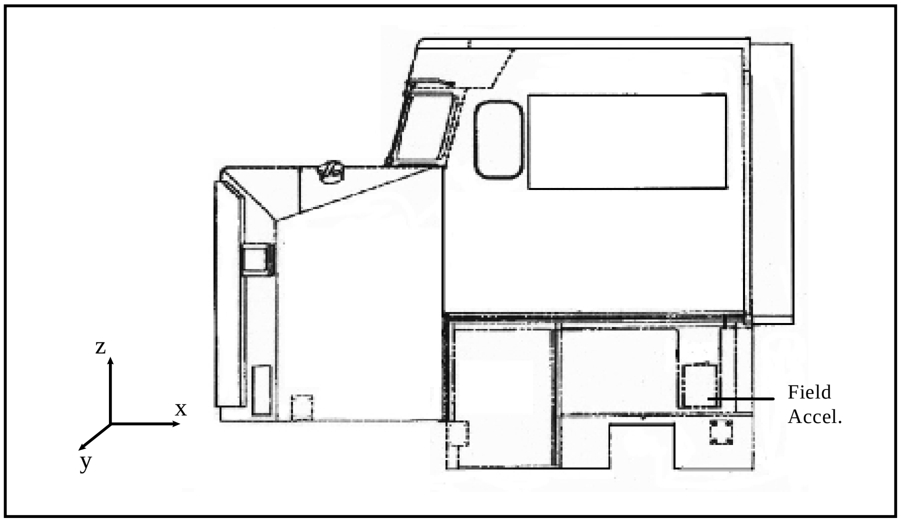


Figure 4.7 Accelerometer B-Side Aft

The result from the experiment is shown in Fig. 4.8. The data displayed in Fig. 4.8 is the Power Spectral Density (PSD) of the acceleration in the z-direction versus frequency plot. The collected field data has low amounts of energy distribution in frequencies above 250 Hz. Below 250 Hz, the energy distributions appear to be random with several large peaks, which most likely represent various driven or structural frequencies. To establish an excitation input signal to the shaker that would generate a similar response at the cab, the "discrete" frequencies from the field data were added to a random signal, and they were proportionally weighted against each other to maintain the relative height of the peaks and the random base signal, as seen in the field data.

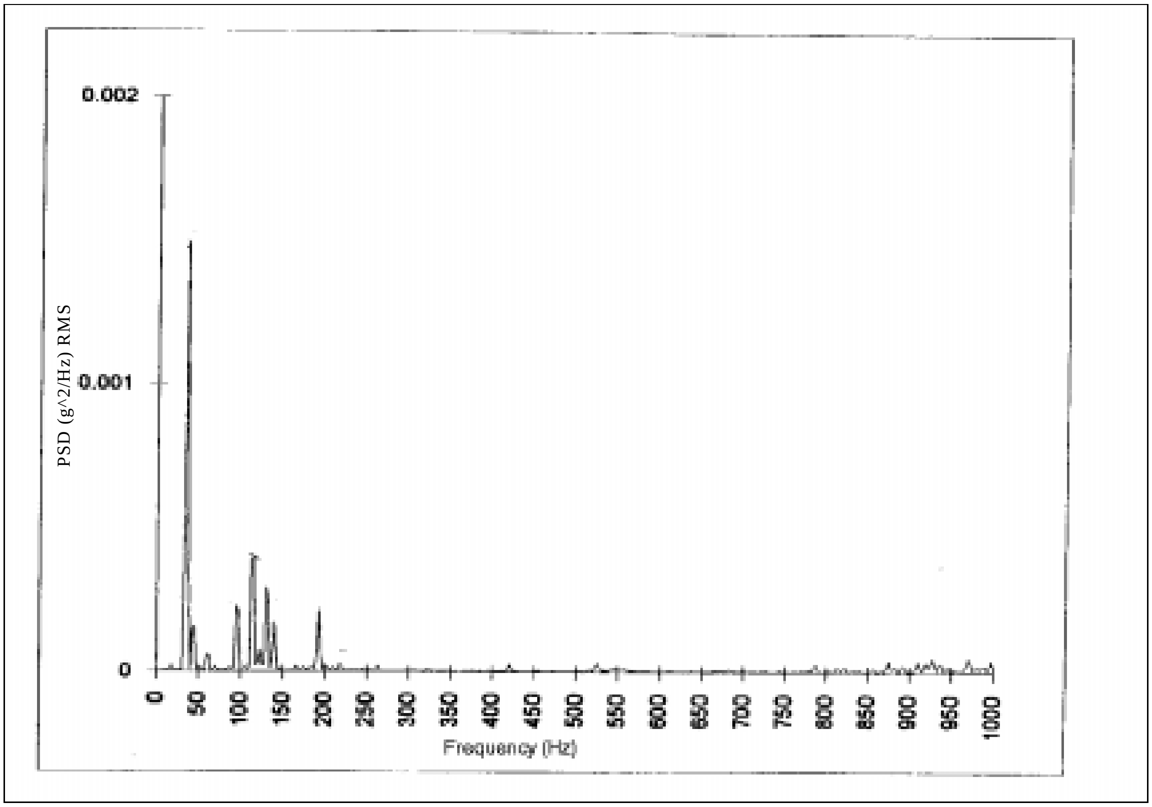


Figure 4.8 Field Acceleration at B-Side Aft Location

The process can be mathematically expressed as:

$$\text{Input} = \alpha_1(\text{Random Wave}) + \alpha_2(\text{Sin}\omega t) + \alpha_3(\text{Sin}\omega t) + \ldots \quad (4.1)$$

where

α_i = the weighting factor to adjust the intensity of each wave.

Random Wave = a white noise random wave.

ω_i = frequencies at which spikes (high peaks) exist in field data.

The input emulates the peaks that were observed in field data, such as the peak at 35.0 Hz due to the second harmonic of the diesel engine. The frequencies of the pure tones are 35.0, 45.0, 95.0, 115.0, 130.0, 140.0, and 190.0 Hz. The signal was generated in

MATLAB as a 30-second text file by combining random noise along with the pure tones as shown in Fig. 4.9. The amplitudes of the pure tones were selected by an iterative process, where the final amplitudes of the excitation input resulted in results similar to the field data.

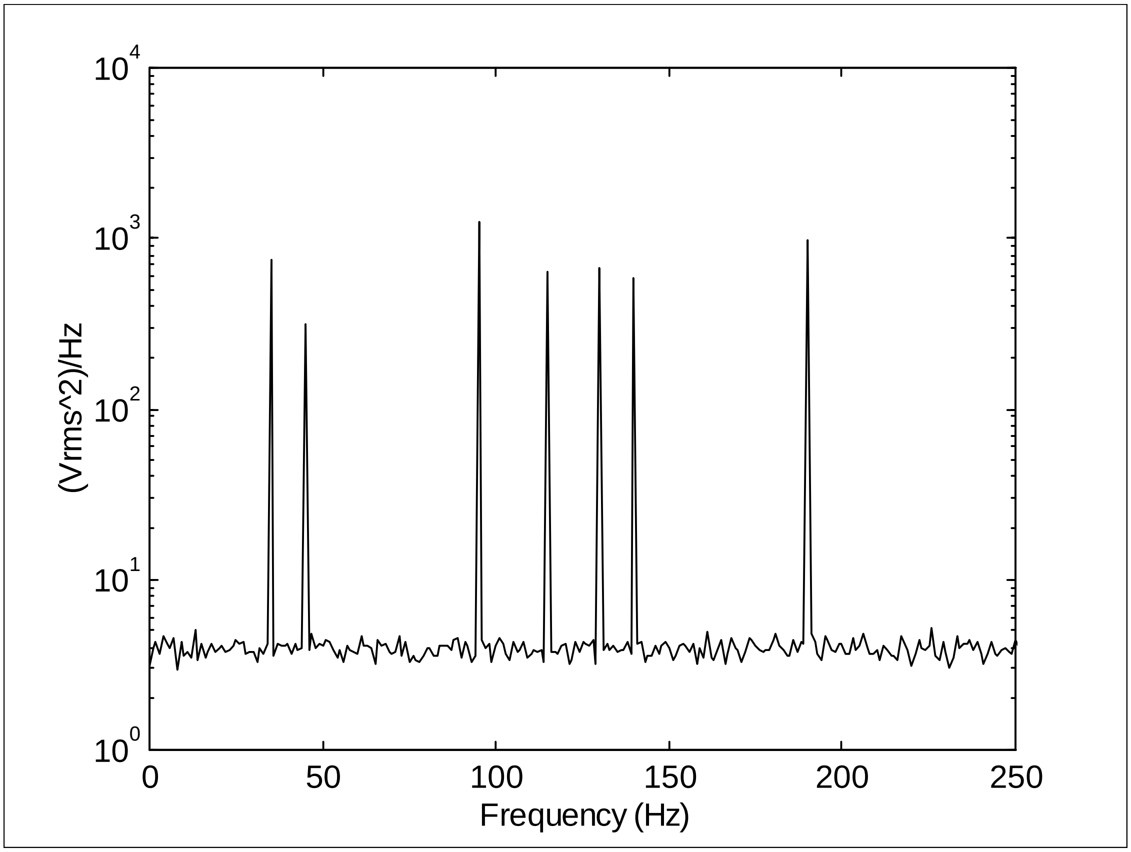
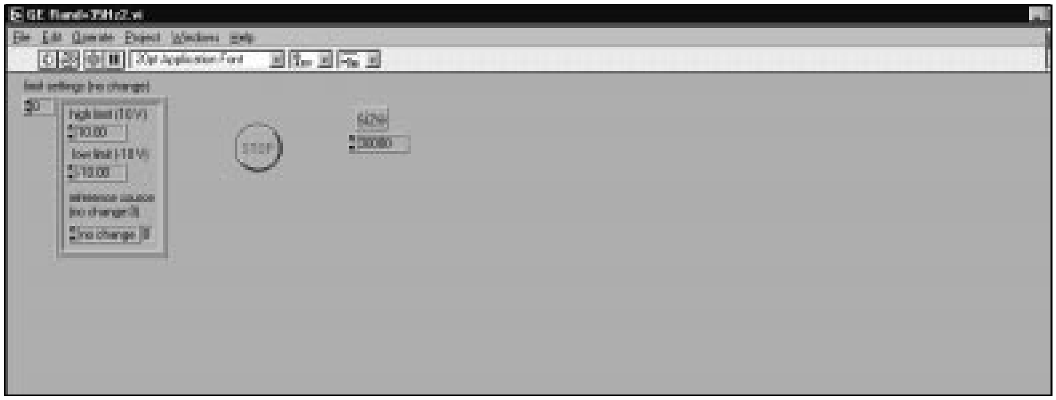
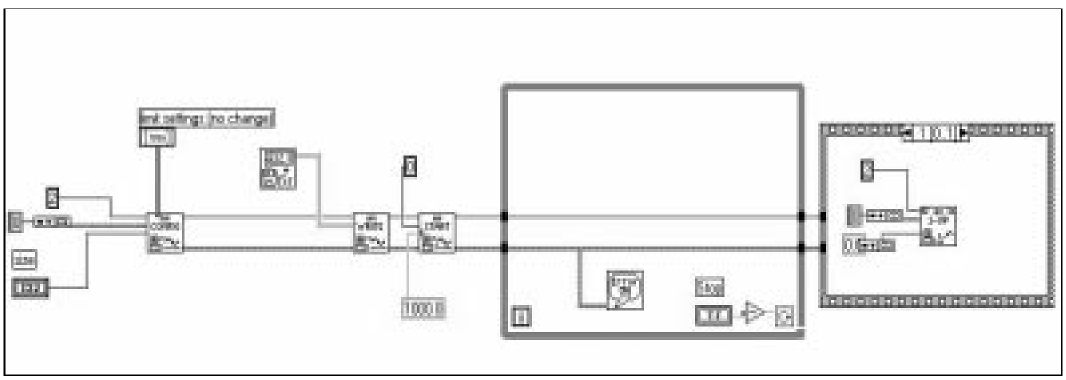


Figure 4.9 Excitation Input to Actuator

The excitation input was used in conjunction with LabVIEW, a graphical programming software by National Instruments used to create programs for instrumentation, in order to provide a continuous external input to the MTS 407 controller, shown in Fig. 3.8. Figure 4.10 shows a screen capture of the LabVIEW file used to govern the input to the controller.



(a)



(b)

Figure 4.10 (a) LabVIEW Input File and (b) LabVIEW Diagram

4.3 Baseline Test Results

Using the input described earlier along with the data acquisition system outlined in Fig. 3.10, input to the cab was nearly duplicated. An experiment consisting of an accelerometer mounted at the B-Side aft position of the hard-mounted cab was run. The

MTS actuator excited the cab using the filtered excitation input signal. A Sony DAT recorder was used to capture the analog signal and convert it into a digital format using anti-aliasing filters. The digital data was next processed in MATLAB, and the results are shown in Fig. 4.11.

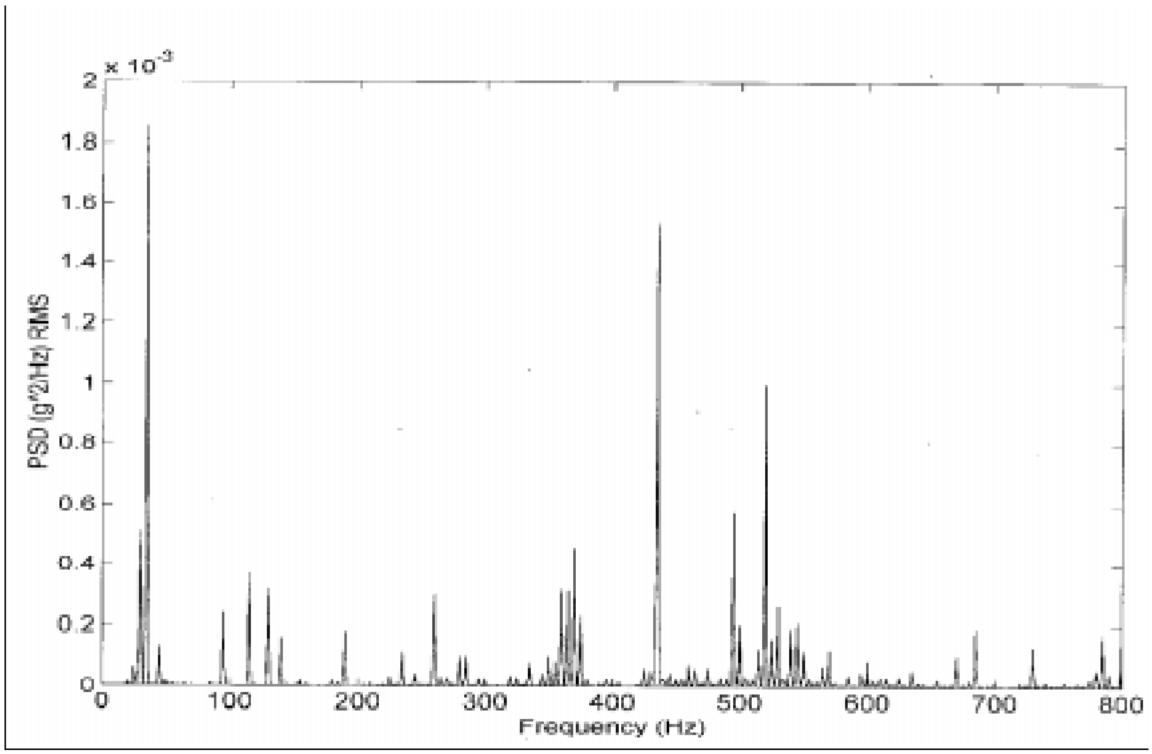


Figure 4.11 Sony Data Accelerometer at B-Side Aft Location

The magnitude and frequency of the peaks below 200 Hz in the figure are the same as the results from the field. Above 200 Hz however, extraneous values that were not shown in field results were collected. It is possible to justify the discrepancy in the results by realizing the difference in the cab configuration for each of the tests. The test that was completed in the field was carried out on a structurally-sound cab. In other words, the cab connections to the sill had not been separated or altered, whereas the experiment that we conducted was on a structurally-modified cab. Although the separation of the cab from the sill was minimized through the replacement of the rubber mounts with steel plates at each corner, nonetheless, the cab boundary conditions had changed, which strongly contributes to the response at higher frequencies.

4.4 Baseline Output Validation

To validate the output and input signals as well as the data acquisition system and the user-defined signal processing program, the HP analyzer was used to acquire data concurrent with the main data acquisition system described earlier. Using a hard-wired analyzer to perform the data computations allows us to check the data acquisition system for any error that may exist in the Matlab programs or Labview routines.

The process outlined in Fig. 4.12 was followed to repeat the experiment that was conducted using the Sony data acquisition system.

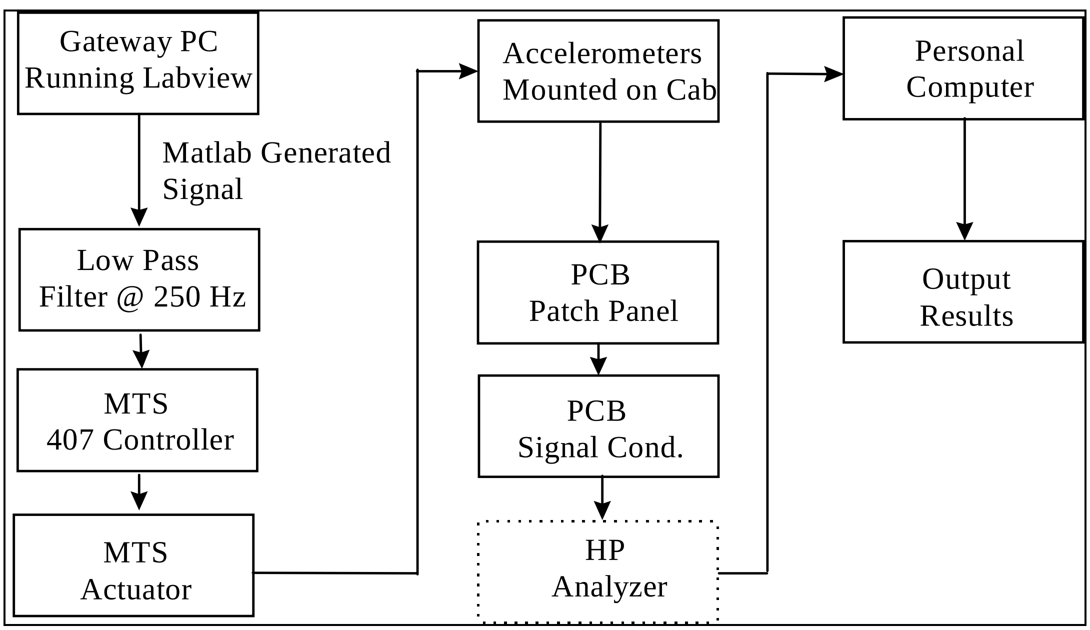


Figure 4.12 HP Analyzer Data Acquisition

As shown in Fig. 4.13, the analyzer setup to validate the data was:

1. Sample the time data and apply an A/D converter to transfer the analog signal into the digital domain.
2. Apply a Hanning window to the non-periodic signal.
3. Obtain Discrete Fourier Transform (DFT) of time history to convert the signal from time domain to frequency domain.
4. Normalize spectrum data to a 1-Hz frequency bandwidth to obtain Power Spectral Density (PSD).
5. Implement an 800-Hz bandwidth along with 800 spectral lines to generate a 1-Hz frequency resolution.
6. Obtain 20 averages of the signal to decrease the external noise level and to accentuate the peaks.

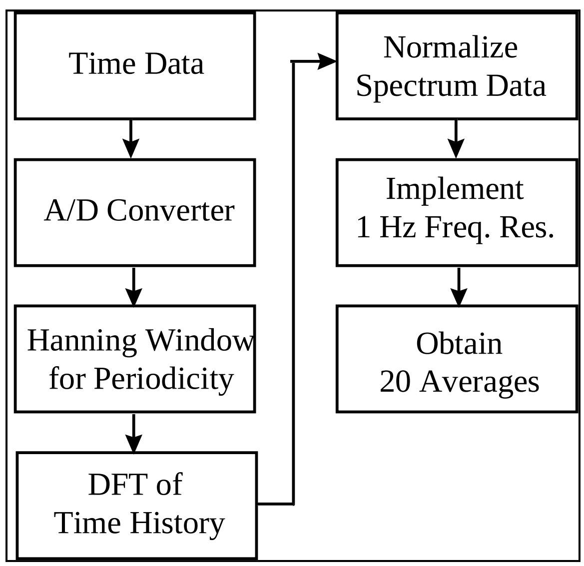


Figure 4.13 HP Analyzer Setup

A comparison between the data from the HP analyzer and the data acquisition system is shown in Fig. 4.14. The results of the data acquisition system and the HP analyzer are plotted on one another to validate that they have identical values over the frequency range.

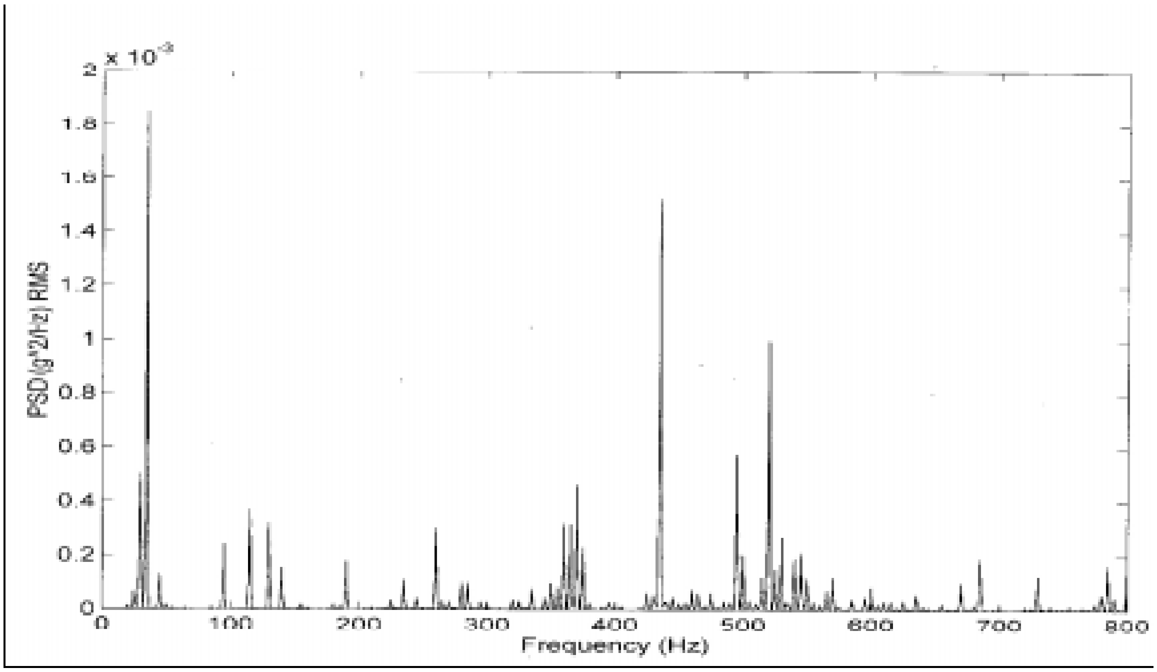


Figure 4.14 HP and Sony Data Accelerometer at B-Side Aft Location

The error between the Sony data and HP data is shown in Fig. 4.15. The difference between the two is minimal over the frequency range 0 to 800 Hz. Statistical data (mean, RMS, standard deviation, variance) values are shown to quantify the resemblance between the two data files.

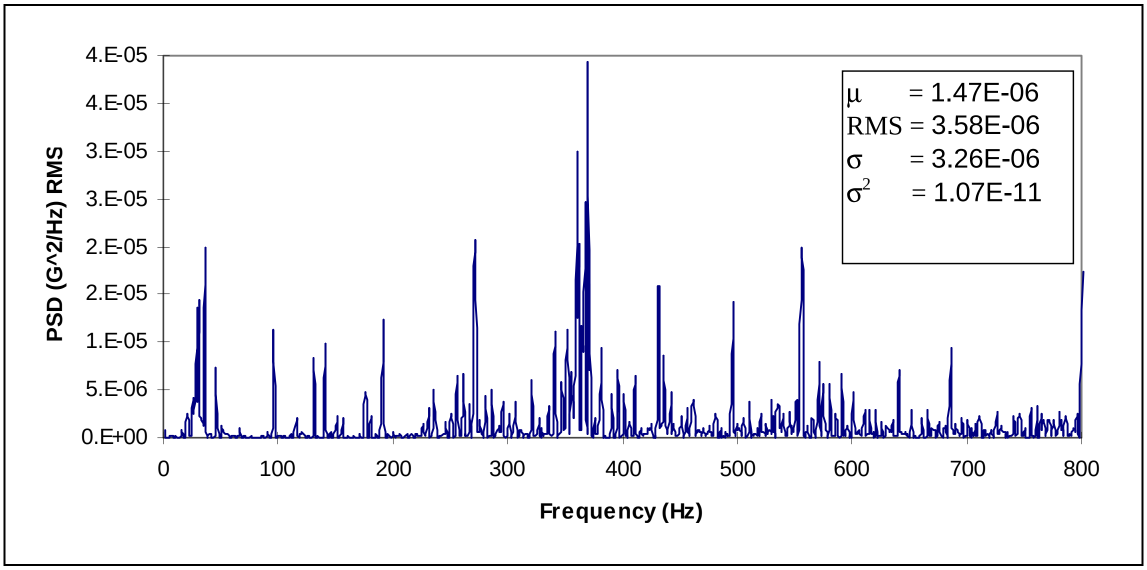


Figure 4.15 Error Criteria for Sony and HP data

4.5 Repeatability

The experiment that was run on the baseline cab was repeated on a daily basis for a period of two weeks under the same conditions in order to establish the repeatability of the data. To establish repeatable conditions when running the experiments, the hydraulic pump was allowed to "warm up" so that the pressure differences in the hydraulic lines could be minimized. To validate the results, the collected analyzer data was consolidated into a single figure. Figure 4.16 establishes a confidence bound on the data by showing the minimum and maximum spectrum values at each frequency for a total of 10 different tests.

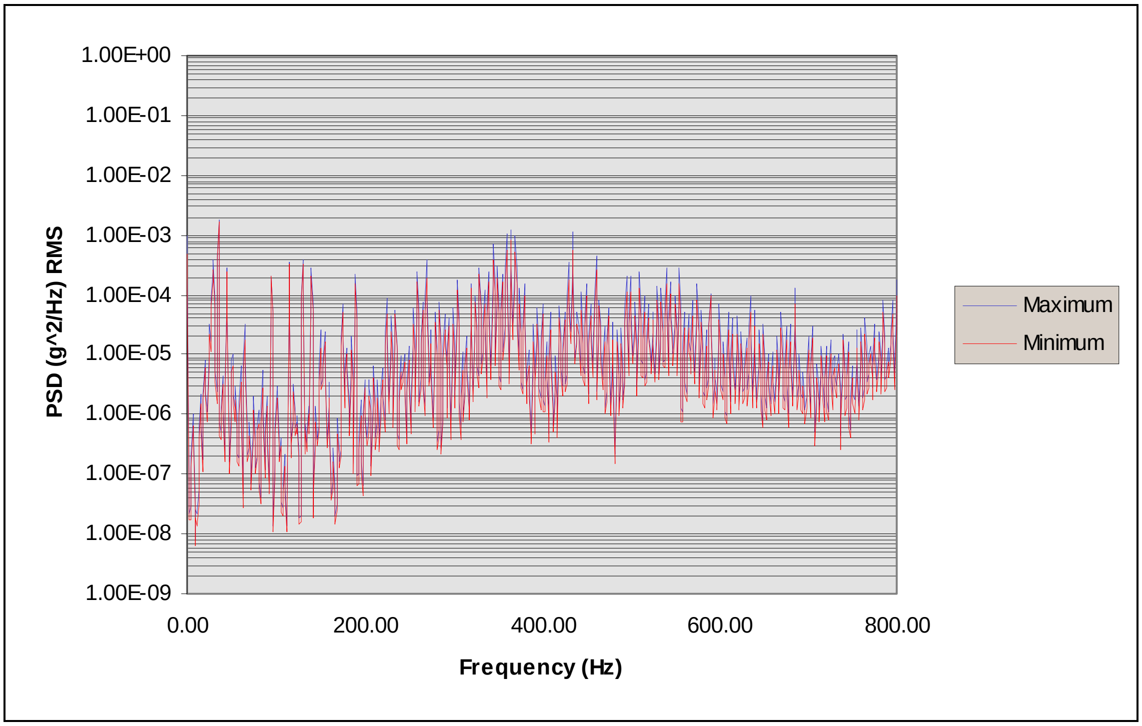


Figure 4.16 Minimum and Maximum Spectrum Values

The figure is shown in a linear scale in the x-axis, and a semi-log scale in the y-axis. Throughout the frequency range of 0 to 800 Hz, the difference between the minimum and maximum spectrum values is minimal. The resulting minimal difference between the spectrum values for the 10 different tests validates the data to be repeatable. Therefore, it can be accepted with a large level of certainty that the results from the baseline cab configuration are acceptable and valid.