APPENDIX B
FINE-TUNING THE SHUNT RESISTORS WITH TESTING

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For the first iteration of testing, the shunts were initially tested without a load resistor. The reason for this was that the internal resistance of the circuit might have been larger than the required load resistance. The addition of a load resistor could have increased the damping level above the desired optimum damping level. The second iteration of testing involved ‘reading’ the results and determining whether the circuit resonance should be increased or decreased. The technique of ‘reading’ the results will be explained here in further detail. For the third iteration of testing, a load resistor was applied, as necessary, to adjust the damping level of the circuit.

To further explain the tuning process, the following figures demonstrate how each of the three shunt circuits used in this study were tuned to decrease the peaks occurring around 120, 150, 240, and 260 Hz.

Shunt Circuit Tuning for the 120Hz Peak

Figure B1 shows the results from the tests required to determine the open-circuit and short-circuit resonance frequencies, which were required to calculate the optimal electrical resonant frequency of the circuit. The difference in resonant frequency between the two responses is about 1.25 Hz. The required inductor resistance was then calculated to be 2307 Ω. The circuit was then tested without a load resistor and compared to the open- and short-circuit responses, as shown in Figure B2.

Based on these initial results, three issues were determined. The first was that the shunt circuit was tuned to the right frequency because the shunted response is symmetric within the short-circuited response curve. Secondly, it was determined that the internal circuit resistance was already too high, or rather, there was already too much damping in the circuit. If there was not enough damping there would be a dip at the resonant frequency and two peaks would occur on either side of the resonant frequency. Thirdly, the vibration levels could not be decreased any more with the PZT, i.e., damping ability was maximized. This was concluded because the shunt was tuned to the right frequency, and the shunt resistance (shunt damping) was already internally too high. Adding more resistance to the shunt would only have increased the shunted PZT plate response.

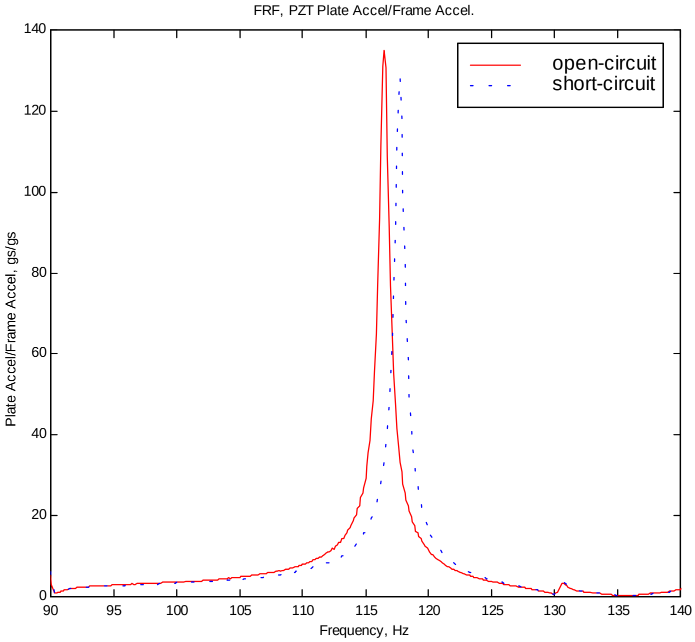

Figure B1. Open Circuit and Short Circuit Response

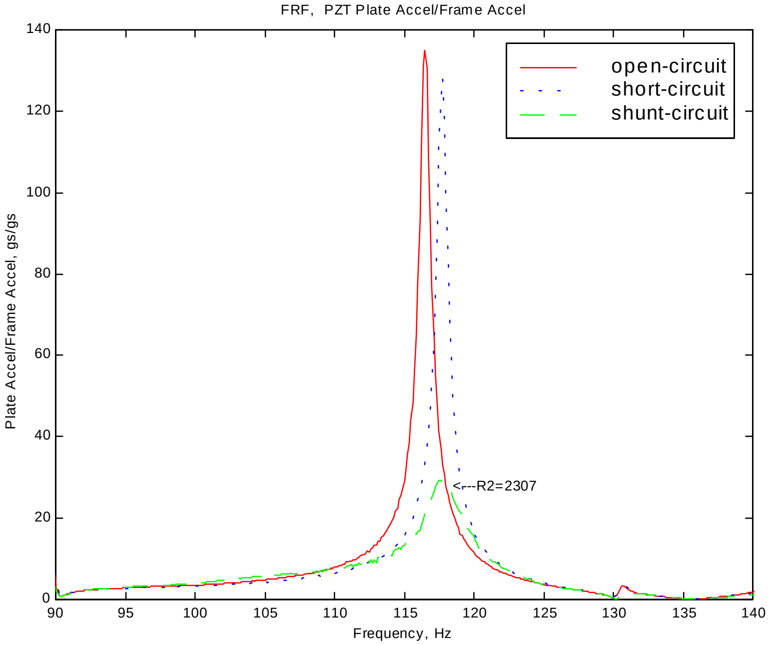

Figure B2. Initial Results Using the Calculated Inductor Resistor Value (w/o Load Resistor)

Shunt Circuit Tuning for the 150Hz Peak

The tuning process of the shunt circuit for the 150-Hz peaks demonstrates the occurrence of under- or over-damping using the shunt circuit. It also illustrates how the shunt circuit was tuned to the right frequency. Figure B3 shows the initial results using the calculated inductor resistor value without a load resistor.

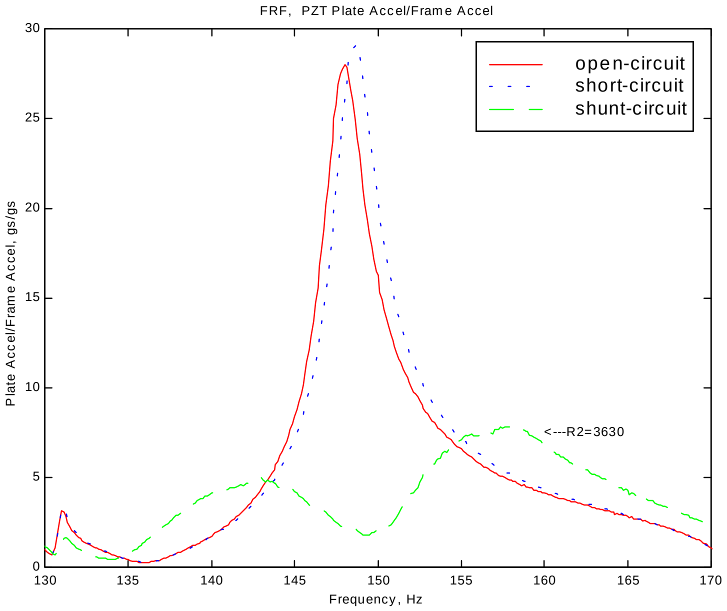

Figure B3. Initial Results Using the Calculated Inductor Resistor Value (w/o Load Resistor)

Two issues were determined from these initial results: the shunt was underdamped, and the shunt still needed more tuning to obtain the optimal frequency. The two peaks occurring in the shunt-circuit response were due to underdamping. The energy at the tuned frequency was displaced but not absorbed because there was not enough damping. The shunt frequency needed to be raised about 2Hz in order for the two peaks to be properly tuned. This was accomplished by adjusting the inductor variable resistor until the peaks were of equal height, as shown in Figure B4.

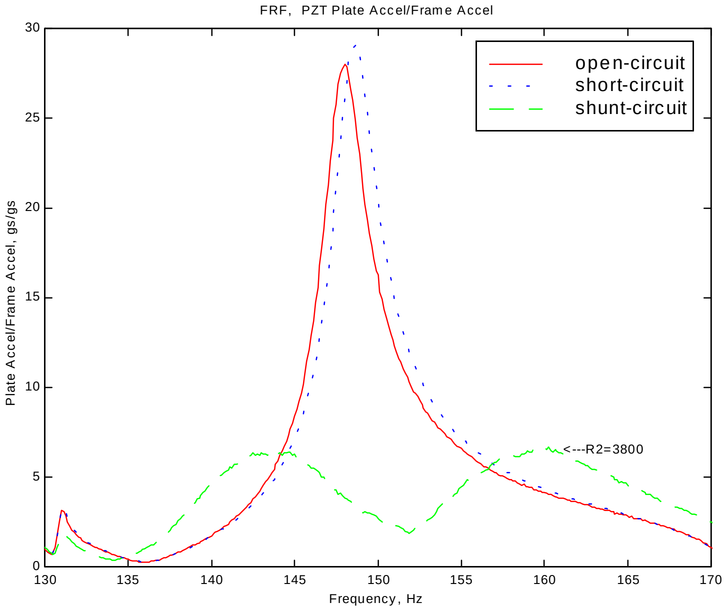

Figure B4. Results of Adjusted Inductor Resistor Value (w/o Load Resistor)

Once the circuit was tuned such that the peaks were of equal height, the circuit was tested again with the calculated shunt resistor as shown in Figure B5. This figure indicates that the system became overdamped, i.e., the shunt resistance was too high.

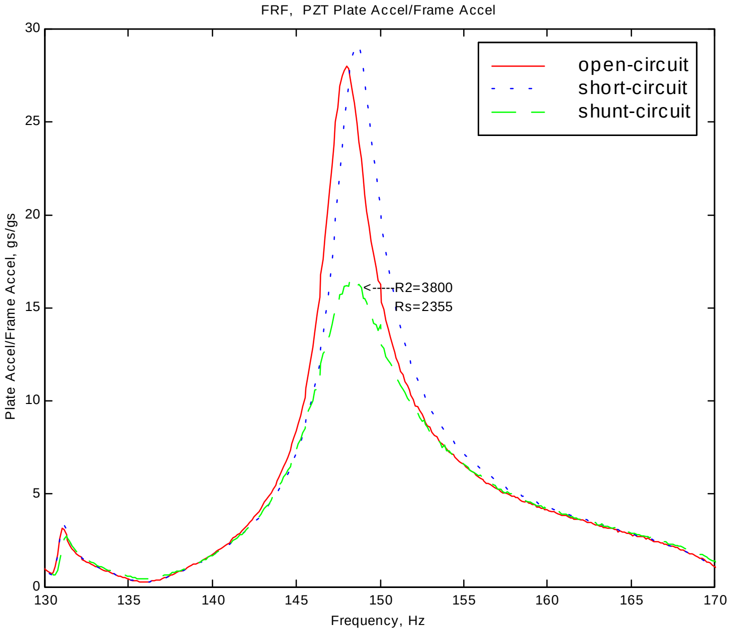

Figure B5. Results of Adjusted Inductor Resistor Value (w/ Calculated Load Resistor)

The shunt resistance was then lowered until there were two barely distinguishable peaks. It should be noted here that the optimal shunt frequency changes as the shunt resistance changes. Therefore, these two peaks may not be of equal height and the inductor must be adjusted slightly again. After the inductor was adjusted such that the peaks were of equal height, the shunt load resistance was raised just until the peaks were no longer distinguishable. This process had to be iterated by making small adjustments to both resistors. An example of an optimal response is shown in black in Figure B6, which illustrates overdamping, underdamping, and the optimal response.

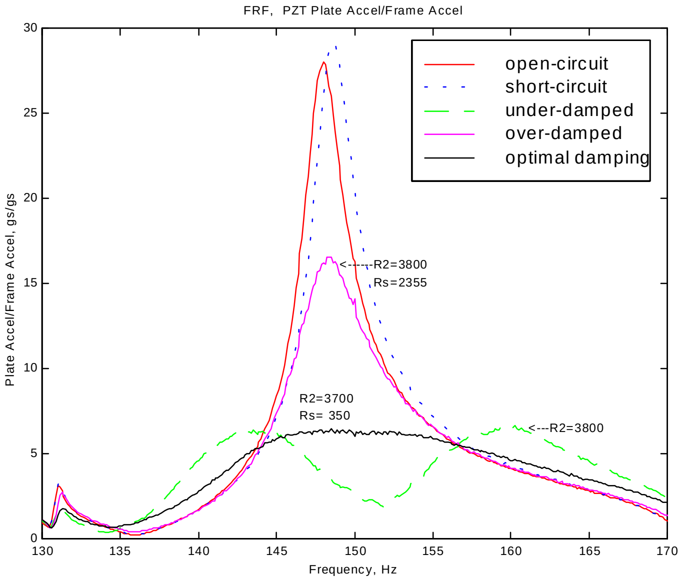

Figure B6. Results of Over-Damping, Under-Damping, and Optimal Response

Shunt-Circuit Tuning for the 240Hz and 260Hz Peak

One shunt circuit and one PZT were used to reduce the vibration and noise levels occurring at 240 Hz and 260 Hz. This was possible because both peaks were close in frequency and were both odd modes. The PZT placed in the center of the plate was located in the center of the sections that deformed during vibration for the modes at both frequencies. The shunt circuit was tuned to a frequency that was between the two resonant peaks. Because of this, the shunt-circuit tuning process was slightly different.

The plate was first tested with the PZT open- and short-circuited, as shown in Figure B7, and the average frequency of the two resonant peaks was calculated for each case. For example, the average open circuit frequency was 250.4 Hz, and the average short-circuit frequency was 249.3 Hz. These values were then used to calculate the shunt circuit resonant frequency. Figure B8 shows the initial results using the calculated inductor resistor value without a load resistor.

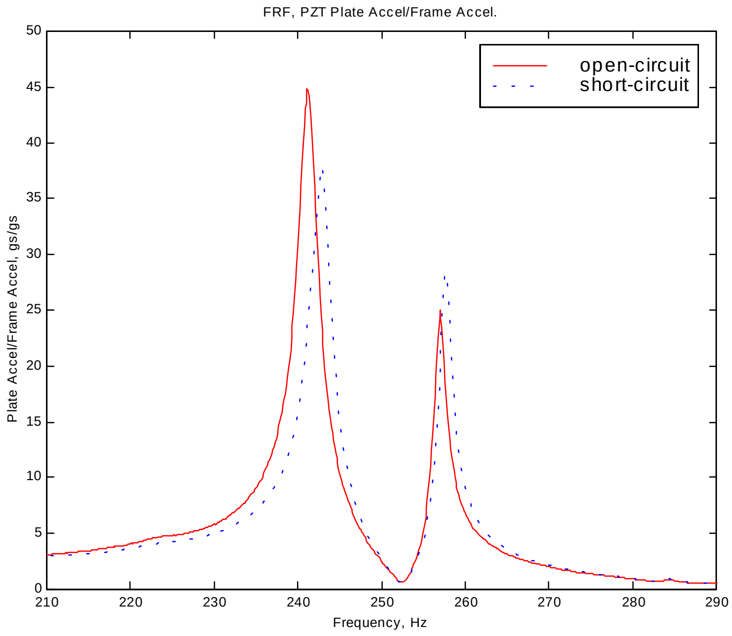

Figure B7. Open Circuit and Short Circuit Response

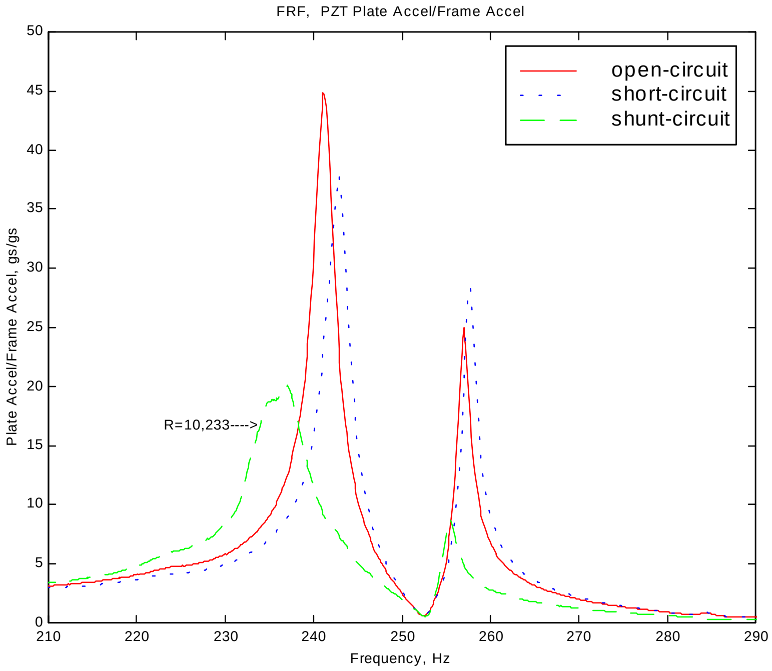

Figure B8. Initial Results Using the Calculated Inductor Resistor Value (w/o Load Resistor)

As with tuning the 150Hz shunt-circuit, the shunt inductor resistor had to be adjusted such that the two peaks were equal. The 240Hz peak has more energy than the 260Hz peak and therefore requires more damping. To account for this, the shunt frequency had to be lowered. Figure B9 illustrates the adjusted shunt circuit response. The resistor value was lowered until the response peaks were of equal height.

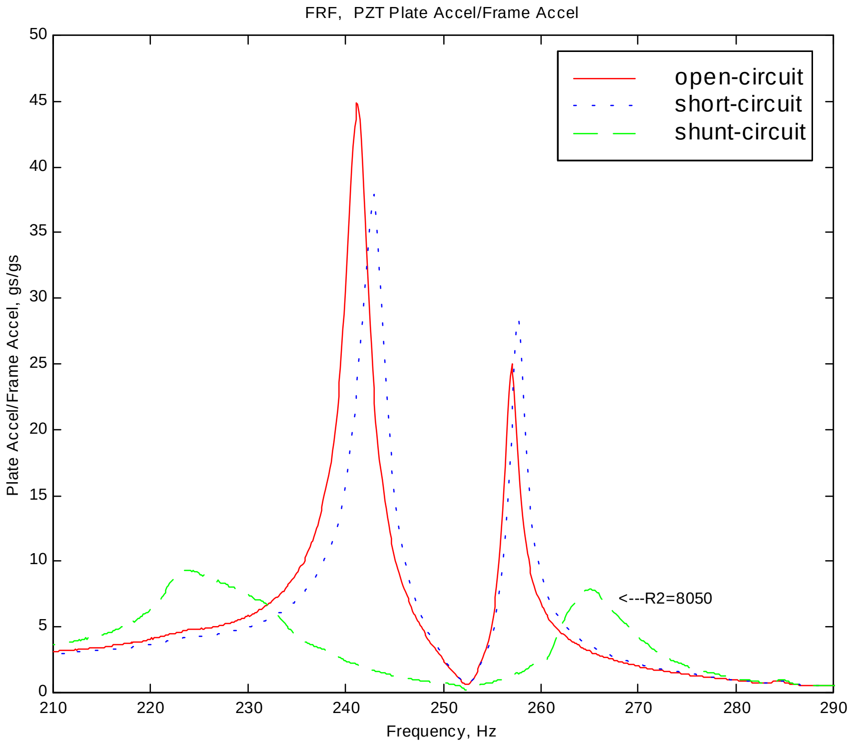

Figure B9. Results of Adjusted Inductor Resistor Value (w/o Load Resistor)

Once the circuit was tuned such that the peaks were of equal height, the circuit was tested again with the calculated shunt resistor, as shown in Figure B10. This figure indicates that the system had become overdamped, i.e., the shunt resistance was too high.

The next step was to decrease the shunt load resistor until the response was minimized. This point was reached when a further reduction or increase in the load resistor value generated a higher response. The optimal value for this case was obtained by reducing the shunt resistor from 1398Ω to 299Ω, as shown in Figure B11.

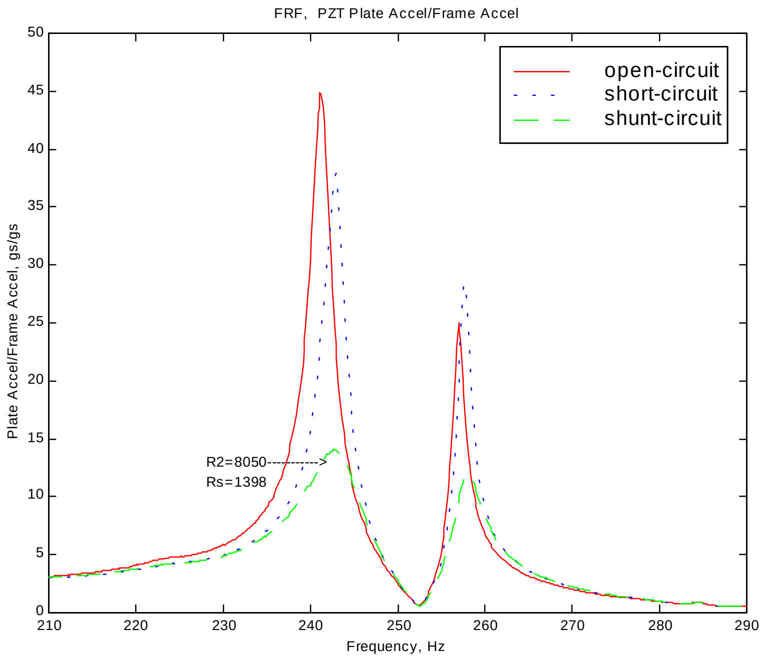

Figure B10. Results of Adjusted Inductor Resistor Value (w/ Calculated Load Resistor)

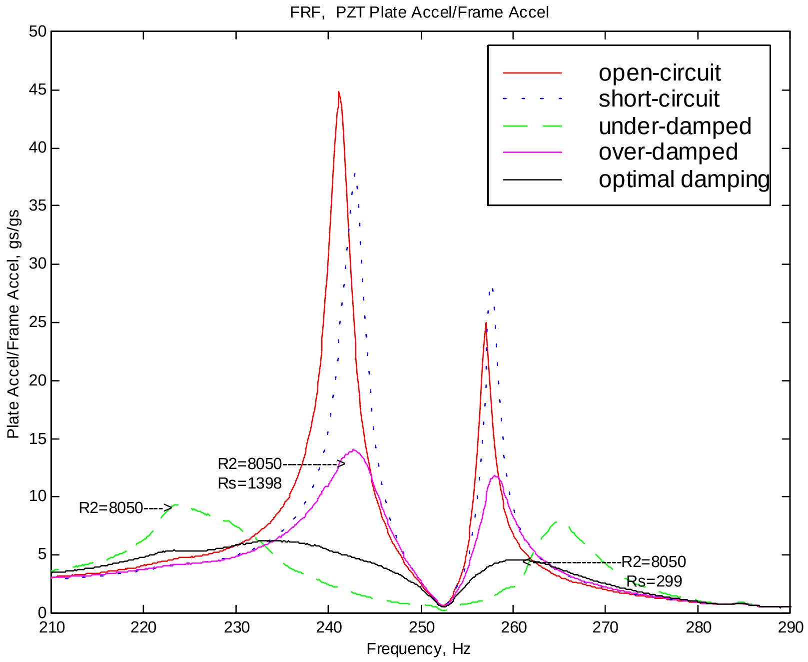

Figure B11. Optimal Response with Adjusted Inductor Resistor and Load Resistor Values

Summary

The shunt-circuit tuning techniques utilized for this study were fairly straightforward and required a minimal number of calculations. Every resonant peak had a different behavior, and successful tuning was largely dependent on recognizing the trends such as those explained here.