

Chapter 8

Conclusions

The purpose of this chapter is to review all of the work that has been completed for this research. This chapter will also summarize and draw conclusions from the laboratory data, and will offer several suggestions for future research.

8.1 Summary

This research started with two specific questions: first, what is the source of the 4.2-Hz peak in the seat response spectrum, and second, what is the source of the seat suspension's poor subjective feel?

In order to answer both of these questions, much preparatory work was completed. A seat tester was built so that the seat could be excited with not only standard input spectra, but also with spectra gathered in the field. Next, all of the test equipment was gathered and set up in the Advanced Vehicle Dynamics Laboratory at Virginia Tech. In order for researchers to become aquatinted with the seat, controller, and MR damper, several meetings were held between Virginia Tech and the sponsor of this research, Lord Corporation, Cary, NC. The purpose of the meetings was to acquire knowledge of the system and share the results with Lord. Finally, a controller prototyping system using a dSPACE DSP controller board and a man-rated system was built at the Lord facility. The dSPACE system allowed for rapid testing of experimental control policies. The man-rated system was intended for better assessing the subjective feel of the seat suspension in the laboratory.

The first major find of this research was an explanation of the 4.2-Hz peak in the seat response spectrum due to the ISO2 input. By comparing the damper current and seat acceleration frequency responses for a pure tone input along with a simple Fourier

analysis of the system, the exact source of the phenomenon was determined. The 4.2-Hz or 3ω phenomenon was determined to be caused by the switching of the damper in response to V_1 , the absolute velocity of the sprung mass, and V_{12} , the relative velocity across the suspension. The parameter ω is the driven frequency or natural frequency of the suspension.

Next, the source of the poor subjective feel of the system was found by extending the focus of the research to analyze the time domain response of the seat suspension. The source of the poor subjective feel was eventually tracked down to be the discontinuous control current that is sent to the damper along with the MR damper's highly nonlinear force vs. velocity performance. A new solution that relatively smoothed out the control current to the damper was proposed and tested. The test results for the new control policy showed a substantial reduction in seat jerk and an improved subjective feel of the seat.

Finally, the seat suspension was tested using groundhook and hybrid semiactive control policies. The groundhook control policy attempts to control the unsuspended body (in this case the base of the seat) in contrast to skyhook control which attempts to control the suspended body. The hybrid control policy combines a skyhook control and groundhook control so that the benefits of each can be combined together. Although the hybrid control is typically designed for two-degree-of-freedom systems, this control policy was tested to investigate the results. No attempt was made to reduce the jerk levels due to either control policy and therefore, the resulting subjective feel was relatively poor.

8.2 Recommendations for Future Research

The first and possibly most important future research that can be performed relative to this study is the subjective testing of the seat suspension. Objectively testing a seat suspension in a laboratory environment and accurately judging how a person will subjectively evaluate a seat is quite difficult. One of the lessons learned from this

research is that the seat acceleration measurements alone do not necessarily provide an absolute indication of the subjective quality of the ride. Other factors such as the individual preference of the riders and their sensory perception to the seat vibrations are quite significant in how well the seat dynamically feels. Lord Corporation has nearly completed the construction of a man-rated seat tester that allows a person to "ride" the seat in the laboratory. This type of testing will significantly help in evaluating the ride that the customer will feel in the field.

Further, algorithms need to be developed to minimize the frequency of the seat reaching its limits of travel. The sensation that is felt when a seat suspension bottoms out can be very annoying at the least, and dangerous at its worst. With the advent of controllable suspensions, we have the ability to predict and prevent these endstop hits. The necessity of endstop control algorithms becomes even more important for suspensions that have good isolation because they often undergo a larger displacements than a stiff suspension. This increases the likelihood of exceeding the damper stroke when subjected to an input with a large amplitude.

Finally, the benefits of extending the scope of the semiactive suspension to include the cab suspension should be researched. Although there exist several analytical and experimental studies on each suspension separately, it is beneficial to combine the control of the two suspensions since their dynamics can interact with each other.