Chapter 8

Conclusions and Recommendations

This chapter summarizes the previous chapters and some discussions relating to the main research results are presented. Furthermore, some future research problems are suggested according to our results and experience.

8.1 Summary

This dissertation concentrated on applying the semiactive technology into vibration isolation. A vehicle seat suspension with application of MR dampers was used as a test rig for research purposes. Thus, it is obviously a nonlinear dynamic system. The previous chapters showed that this research involved four main aspects to further study semiactive technology: semiactive damper modeling, nonlinear dynamic analysis, control systems design, and laboratory implementation. In every aspect, we tried to come up with our ideas to solve some problems we encountered in the research.

First of all, throughout the data analysis, a nonlinear non-parametric model without using stiff differential equations was developed for magneto-rheological dampers. The model uses a series of analytic functions to accurately capture different nonlinear characteristics that MR dampers exhibit. The advantages of this non-parametric model are that the model is

- continuous and differentiable, and
- numerically tractable

Thus the model is useful for system evaluation and control algorithm development. For example, since most optimization algorithms are based on gradient search methods, the optimization speed can be improved if the model functions are differentiable. From another point of view, if the model includes stiff differential equations, an extremely small step size is required in order to guarantee the simulation stability and further improve the numeric accuracy. More importantly, for implementing an efficient real-time controller, a low sampling frequency is preferred for reducing the hardware cost, especially for mass production. Thus if a controller needs partial incorporation of a model which includes such as stiff differential equations, it may be even impossible to implement such a controller, due to requiring expensive high-speed hardware. Therefore, it is important to build an accurate model by using appropriate functions. Such modeling work is challenging especially for nonlinear phenomena.

At the first stage of this research, we focused on the implementation of the traditional skyhook control policy on a vehicle seat suspension. Two observations from both experimental data and simulation results were deeply investigated:

- The experimental seat suspension had poor subjective feeling. It was observed that there were a lot of acceleration jerks in the time domain. Why? How to get rid of them?
- Higher harmonic frequency components were observed in the frequency domain even with pure-tone excitations. Where were they from?

Through the analysis of the relationships among dynamic signals in the time domain, it was found out that the poor subjective feeling was caused by the discontinuous control current that is sent to the MR damper with a highly nonlinear force vs. velocity performance. Based on the analysis, two methods (i.e., no-jerk skyhook and skyhook function) were developed to improve the traditional skyhook control policy. The testing results showed that both methods were effective for eliminating acceleration jerks. The other problem of the 3ω peak (i.e., the higher harmonics) was also clearly answered with the aid of a signal flow chart by applying a pure tone excitation in the semiactive skyhook systems.

At the second stage, the research concentrated on the further development of the semiactive control technology with emphasis on the adaptive concept. A new adaptive control algorithm was developed for one class of nonlinear random vibration systems.

This adaptive algorithm can deal with the complicated nonlinearities such as saturation, hysteresis, deadband and backlash without linearization. Since a model is the cornerstone for adaptive control design, it is critical to model the system properly. Several standard nonlinear models are available but too complicated even for the one DOF magneto-rheological seat suspension. A second order differential equation including a nonlinear damper model was used to describe the studied problem. Based on such a model, a complete adaptive algorithm was developed.

For research purposes, simulation was firstly performed to evaluate the feasibility of the proposed adaptive algorithm. A parametric approach was adopted to study the effects of different parameters of the adaptive algorithm on the vibration isolation performance. The simulation results showed how to simplify the adaptive algorithm without adversely sacrificing the performance. These results were also important as the guidance to implement the adaptive algorithm in the lab.

Finally, the developed adaptive controller was implemented on a vehicle seat suspension in the lab. The experimental work included circuits design, model simplification and verification, laboratory testing, and data processing. For functional demonstration, three different excitation signals were designed: pure tone, sweeping sine, and ISO combination. By using these excitations, we could easily investigate whether the adaptive algorithm worked properly with the measurement signals of the seat acceleration and relative displacement. Firstly, the seat suspension model was simplified and verified as a base-excited vibration system with one vertical spring and one vertical damper. The testing results showed that adaptive controller based on the simplified model could work properly, even if some dynamics was not included, for example, an optimal non-parametric MR model was used to estimate the damping force because no force sensor was used in the experimental test rig.

8.2 Proposed Future Work

Since the advent of the semiactive vibration control in the early of 1970s, it has been advanced with the progress of other technologies, such as computer technology, nonlinear dynamic analysis techniques and smart materials. But the semiactive technology is not widely applied in industry, even though many research results have shown its advantages over passive and active approaches. Therefore, a further systematic research is a must from semiactive devices to systems design. Even though this research has made a progress in some aspects of the semiactive technology application, there are several issues related directly to this research to be solved or further developed in the future.

The first issue is about the application of the proposed non-parametric model to the ER fluid and its devices, because the ER fluid exhibits nonlinear dynamics similar to the MR fluid. Moreover, it is still necessary to investigate the possibility of using other approaches or functions to simplify the model due to the complexity of the functions in the proposed model. Even though our results showed that a good model may be able to replace a physical sensor for the semiactive adaptive control systems implementation by avoiding some possible measurement difficulty and high cost, the feasibility for other semiactive systems has to be further evaluated in the future research.

In this dissertation, even though a signal flow chart was used to successfully analyze the nonlinear dynamics inherent with the semiactive systems, this method has to be developed more systematically, or represented more mathematically. Then the idea may be able to be applied to other nonlinear problems. As is well known, perturbation methods can be employed to analyze some nonlinear dynamic systems accurately. Some other methods are also available. We should investigate their applications in the analysis of semiactive systems.

The proposed adaptive control algorithm has been successfully implemented on a semiactive vehicle seat suspension. Furthermore, since the adaptive control algorithm is developed from a general mathematical description, we hope this approach can be applied to other control systems development, for example, multiple DOF vibration systems and continuous structure vibration problems. The immediately induced issue for these applications may require research on parallel algorithms on multiple DSP chips to achieve real-time control. For the further extended application, the most concerned is about the possibility of its application in active control systems. If so, the system stability has to be analyzed properly in another way.

Furthermore, if we want to develop semiactive adaptive vehicle suspensions to become commercial products, their cost performance and market research have to be evaluated. Thus, more field-testing has to be done to explore the semiactive adaptive vehicle suspension design. For example, how do temperature extremes affect the dynamic system performance? Do we have to include more factors such as temperature in the MR suspension model? Other related helpful problems also have to be explored. Can we develop much simpler formulation of adaptive algorithms for easier implementation? Is it necessary to adopt nonlinear control laws to improve the performance? How to use other smart materials to develop other kinds of semiactive devices? Further study of these problems can boost the application of magneto-rheological dampers and semiactive control.

Finally, we can say that if appropriate semiactive control technology can be applied together with such as computer technology and smart materials, new generation of intelligent vibration control products, such as intelligent vehicle suspensions and intelligent mounts, will become available in the market.