CHAPTER VII

DISCUSSION OF RESULTS AND CONCLUSION

7.1. Summary of the Research

In this thesis, a simulation-based leaf spring model was created to study the effect of leaf spring suspension parameters on vehicle ride comfort. The main objective is to build a simulation model for ride comfort prediction from leaf spring parameters which can be used in design process, in an attempt to save time, cost, and eliminate uncertainties that may exist in field experiments. The basic idea for the model was using five massless links connected with rotational stiffnesses with the axle mounted at the center of the middle link. For a leaf spring modeling, a massless approximation is reasonable since the masses involved in rigid axles, wheels and the body of the vehicle are considerably higher than the mass of the leaf spring. The model was then verified by using a leaf spring test rig that can measure vertical static deflection of leaf spring under static loading condition. Some experiments were carried out to compare the results with those of the simulation's and finally obtained the values of the unknown parameters. The quarter-car model, with sub-system which represents the characteristics of suspension system was used to study the response of the vehicle to the road profile excitation, based on road surface roughness classification approved by ISO 8608 and the completed vehicle suspension model was constructed by including the leaf spring model into a quarter-car model. The synthetic road profile, representing road irregularities for five road classes were generated by the simple road model as the input of the system at constant velocity of 60 km/hr. For simulation subjected to different types of roads, the shackle angles were varied from 60 degree to 120 degree measured counterclockwise from the horizontal plane. The vertical acceleration of the suspension was captured and used to calculate ride comfort value in the form of weighted RMS acceleration by using the frequency weighting technique recommended by ISO 2631-1.

The overall results show that ride comfort is better on smooth road with gradual changes from "very good" to "poor" road and sudden increase for the "very poor" road. The values obtained from the non-linear and linear leaf spring suspension model are slightly different from each other. The worst case of ride comfort is in the "extremely uncomfortable" area for all values of shackle angles which is highest at 90° and lowest at 70° while the best one was found at 60° of shackle angle by simulation of the "very good" road. the linear model tends to produce higher value in degree of discomfort. At the position 90° of shackle angle at initial installation, the nonlinear leaf spring behaves similarly to the linear leaf spring because there' no effect from the longitudinal load when a leaf spring is perpendicular to the datum line.

7.2. Conclusion

The non-linear leaf spring has significant effects on the leaf spring's kinematics as the results show that ride comfort values depend on suspension' s characteristics. The results obtained from both non-linear and linear leaf spring suspension are different and the linear model tends to produce higher degree of discomfort. This is reasonable as in nature, friction always resists movement in mechanical system so that the proposed leaf spring model is reliable. For standard tool used in the research, the use of ISO 2631-1 for ride comfort evaluation results in the acceptable values compared to the level of the suggested comfort/discomfort. Indices of comfort are calculated taking into account the human sensitivity. The examples show that the proposed comfort indices depend on leaf spring suspension's parameters and, hence, are useful design tools.

7.3. Further Recommendations

Firstly, the recommendations shall be commented on the process of the leaf spring modeling. In the research, the completed leaf spring model includes the geometrical property and hysteresis/friction effects which cannot be neglected. The verification of the leaf spring was made by identifying the leaf spring's parameters based on the comparison of the experimental results with those of the simulation's which is just the trial and error approximation. The recent work was lack of sufficient data in the transition state which might be due to the limitation and ability of the leaf spring test rig that can allow for static testing only so that the model does not capture well in the transient state transition. In the identifying procedure of model's parameters, the method of optimization and numerical calculations can be employed to provide better results and more accurate values Apart from this, some obstacles still exist to limit the performance of the test rig such as misalignment between the hydraulic actuator and the force sensor must be eliminated in order to provide better accuracy. For comfort study, the focused parameter taken into consideration was only the shackle angle which is just one example of many factors that can contribute to nonlinearities of the system. The other component such as bushing which has not yet been included into the present proposed model can be added to represent more about the leaf spring's characteristics such as the work of Hoyle [17]. For the hysteresis modeling, there are different models of friction available at present, apart from Dahl's model which can be used and compared among one another to prove the reliability of the proposed model. The detailed description and comparison can be found in ref. [18].

In the ride simulation, road input profiles were generated randomly by a stochastic process which was illustrated by a power spectral density (PSD) function. The other road model in time domain such as white noise filtration method proposed by Zhang Yonglin et al. [19] can be applied with the proposed leaf spring model in order to see different results. Furthermore, the validation of the leaf spring model by field experiment has not yet been performed. The real road irregularities can be collected and used with the model in order to compare the results with those obtained from real situation. The various standard methods for ride comfort evaluation [8] can be employed with the experiment and simulation data to prove the reliabilities of the results. Finally, the fulfillment of the research can be made through the other ride comfort measuring scheme that is the subjective measurement in order to relate the design parameters of vehicle with the human sensitivity on ride comfort.