International Journal of Automotive and Mechanical Engineering (IJAME)
ISSN: 2229-8649 (Print); ISSN: 2180-1606 (Online); Volume 11, pp. 2495-2503, January-June 2015

DOI: http://dx.doi.org/10.15282/ijame.11.2015.29.0210

RIDE COMFORT SIMULATION OF A VEHICLE EQUIPPED WITH SEMI-ACTIVE STEERING SYSTEM

M. Maharun*, M.B. Baharom and M.S. Mohd

Center of Automotive Research and Electric Mobility (CAREM),
Universiti Teknologi PETRONAS,
31750 Tronoh, Perak, Malaysia
*Email: muin.maharun@petronas.com.my
Phone : +605-3687014; Fax : +605-3656461

ABSTRACT

This paper presents a ride comfort analysis for a vehicle equipped with a novel steering system called the Semi-Active Steering system (SAS). Current vehicle steering systems, especially in cars which are equipped with a rack and pinion steering system, cause discomfort to the driver whenever the vehicle is driven on an uneven surface or over a pot hole. The driver may feel the vibration on the steering wheel due to the mechanical linkage of the rack and pinion steering system. The unique design of SAS which omits the solid linkage and replaces it with a low stiffness resilient shaft has made it possible to reduce the discomfort felt by the driver. In this research, two vehicle models were built in vehicle simulation software; one with a normal rack and pinion steering system and the other with the SAS system. Both vehicles were simulated on a four-post suspension test rig. Vibrations and steering wheel feel were observed and compared between the two models. The results show that the vehicle with the SAS system managed to improve the comfort by reducing the amount of vibration at the steering wheel. The findings may be useful for car manufacturers to improve the ride and comfort of the vehicle.

***Keywords*:** Semi-active steering; ride comfort; steering vibration; four-post suspension test rig.

INTRODUCTION

Since the early beginning of automobile history, one crucial subsystem that allows the vehicle to be maneuvered is the steering system. The steering system is meant to provide directional control for the driver in response to the driver's command input [1, 2]. It is also responsible for providing vehicle safety, steering quality and steering control [3]. The early design of steering system that was introduced caused many difficulties and inconvenience to the driver especially when trying to park the vehicle at low speed. Furthermore, as the automobile industries expanded, vehicles with bigger chassis and engine capacities with higher power and speed were introduced. This led to the need for drivers to use a lot of strength in order to overcome the higher rack load due to the larger engine size [4]. In response to this issue, a steering system with hydraulic power steering (HPS) assist was introduced by the Delphi Saginaw steering system. This was the world's first steering system equipped with hydraulic assist. This system was then implemented by General Motors in its vehicles in 1953 [4]. But hydraulic steering has certain drawbacks such as the tendency to pipe leakage, it requires more power from the engine since it is operated by a hydraulic pump, and it requires frequent maintenance of its power steering oil [5]. These drawbacks have led automobile manufacturers to shift from the trend of the HPS steering system to electric-powered steering (EPS). The difference between EPS and HPS is that it utilizes an electric motor to actuate rather than a hydraulic pump. The advantages of EPS include that all the torque from the electric motor is directly transferred to turn the wheel, meaning that there is less loss [6]. It was also reported that adopting this steering system can reduce the engine load and thus reduce the fuel usage by 5 to 15% [7].

All the said steering systems, namely the conventional steering system, HPS and EPS, have almost the same basic design configuration, where the steering wheel is connected to the rack and pinion system through multiple solid links or the steering column. With advances in active control systems, there is another type of steering system that utilizes a totally different design. This steering system is called the Steer-by-Wire (SBW) steering system. It uses an electric controller in place of a direct mechanical linkage or steering column to steer the wheel [8]. The obvious difference between this design and the conventional steering design is the removal of the steering shaft and column, which means there is no physical connection between the steering wheel and the rack and pinion setup [9, 10]. The advantages of having SBW installed are that it allows improved handling performance at high speed [10], the steering ratio and effort to turn the steering can be adjusted [11], and it also provides freedom in terms of packaging, as a more space-efficient steering design can be introduced [11, 12]. There are several designs of SBW available and these are discussed by researchers in [8]and [13].

Whilst this design has been accepted by most automobile manufacturers, there are still some issues that may cause inconvenience to the driver. One factor that may cause discomfort to drivers is vibration. Vibration may appear at various locations in an automobile. In this research, the vibration especially at the steering wheel is studied. The factors contributing to a vibration problem at the steering wheel are an unbalanced wheel, radial non-uniformity of the tire, the front suspension's longitudinal flexibility and also the steering friction attenuation phenomenon [14]. The reason why vibration is felt at the steering wheel is because a conventional steering system comprises a steering wheel and steering column. These components are subjected to vibration caused by the road and engine excitation. According to researchers [15-17], in order to eliminate the first mode of vibration, a tuned mass damper is added in series with a steering column, thus reducing the vibration transmitted to the steering wheel.

The vibration that occurs at the steering wheel is due to the fact that the steering wheel is connected to a steering column. In this paper, a study of ride comfort due to vibration at the steering wheel is discussed. The research will focus mainly on the effect on the vibration of LSRS installed at the steering system. The type of steering system used in this research is a novel steering system called the Semi-Active Steering system whose initial design concept was discussed in [18]. A simulation was conducted by using the MSc ADAMS/Car where four-post test rigs were used. Figure 1 shows the simulation setup in MSc ADAMS/Car software. Two vehicle assemblies, one with a normal conventional steering system and the other with the SAS system installed, were used in the simulation. The results were compared between these two vehicle assemblies.

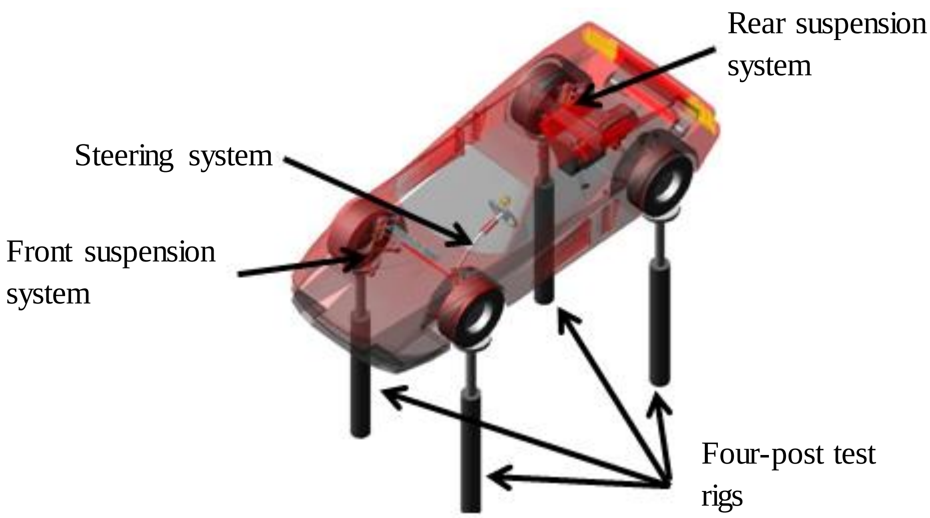

Figure 1. Four-post test rig simulation setup in MSc ADAMS/Car.

DESIGN AND MODELING OF THE SAS

Based on the preliminary design of the SAS system discussed by Baharom, Hussain [18], the SAS system comprises five (5) main components, namely the LSRS, power motor, reaction motor, sensors and controllers. Figure 2 exemplifies the proposed design construction of the SAS system. The most complicated part of this research is to model the LSRS as closely as possible to the actual behavior of the LSRS. The LSRS should possess enough stiffness and torsional rigidity so that it can flex and at the same time the driver can turn the steering wheel according to the desired input. The models of the conventional rack and pinion steering system, the SAS model by Baharom, Hussain [18] and the proposed SAS modeling used in this research are shown in Figures 3(a), 3(b) and 3(c) respectively.

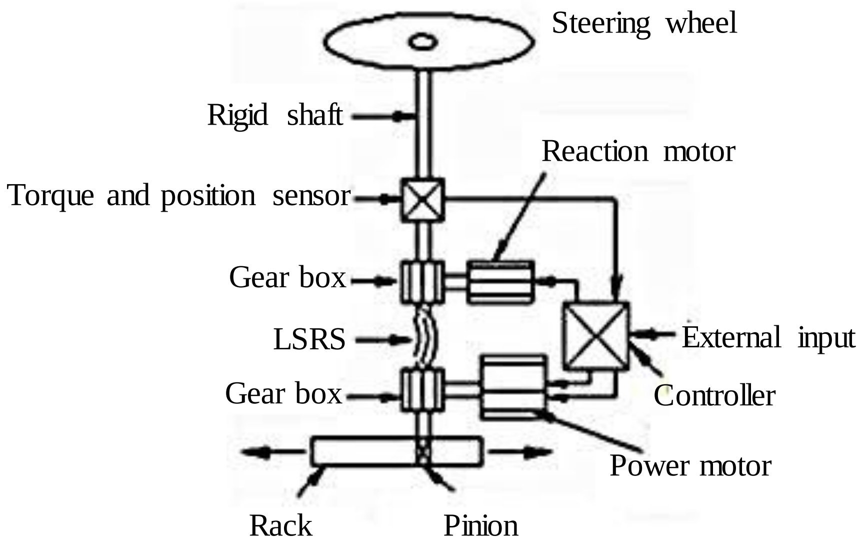

Figure 2. Schematic of the SAS [18].

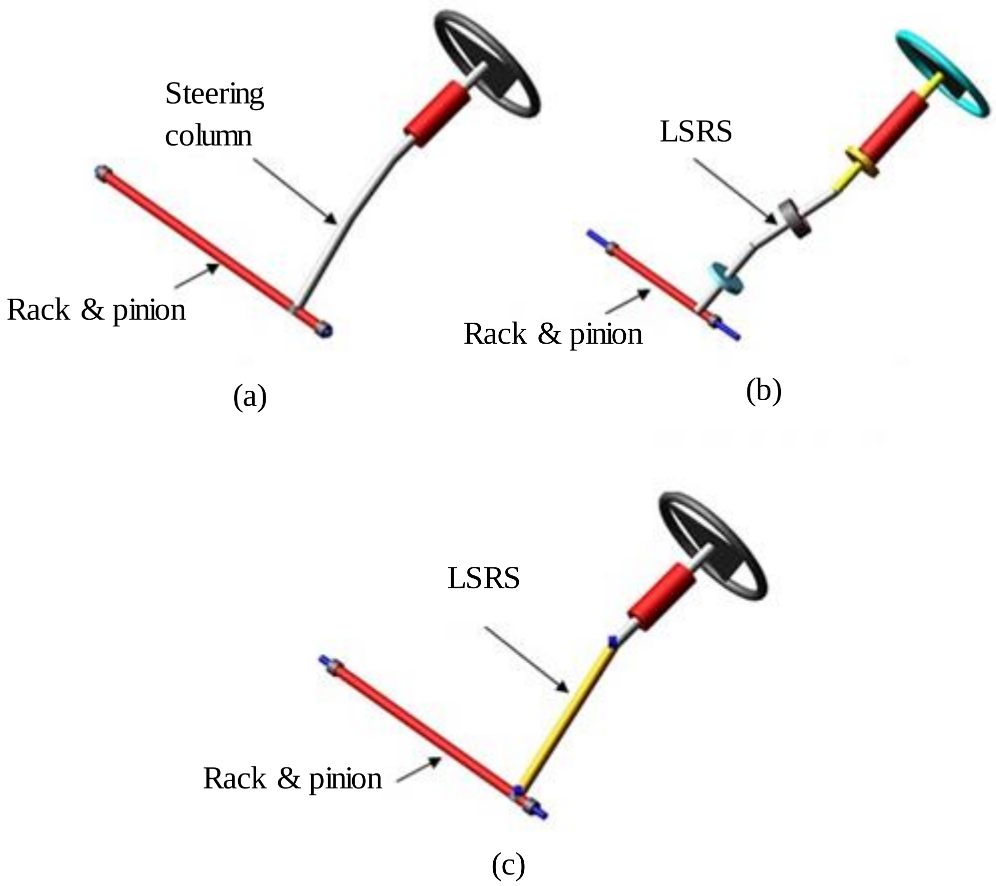

Figure 3. Steering model: (a) conventional rack and pinion model, (b) SAS model by [18] (c) proposed SAS steering model in this research.

Figure 3(a) shows the normal modeling of a rack and pinion steering system in MSC ADAMS/Car software. It comprises steering columns which connect the steering wheel and rack and pinion assembly. For LSRS modeling purposes, these columns were replaced with a shaft that is flexible but at the same time has enough torsional rigidity so that the rack and pinion will turn in response to the driver's steering wheel input. Figure 3(b) is the SAS model proposed by Baharom, Hussain [18]. As observed from Figure 3(b), the LSRS is modeled with two columns connected with a bushing that has a certain stiffness. The method of modeling the SAS as proposed by [18] is good for preliminary research, but it does not actually represent the actual behavior of LSRS since there are still two solid columns used in the modeling. Figure 3(c) is the SAS system proposed for this research. The LSRS was modeled by utilizing the ADAMS/Flex program that was run simultaneously with ADAMS/Car. The model has the same stiffness as the researchers [18] proposed in their research. The shaft was meshed and possesses certain modes that reflect the actual behavior of the actual LSRS. The modes that were assigned to the shaft were mode 7 and mode 8, which have frequencies of 893.8 Hz and 941 Hz respectively. Figure 4 shows the mode shapes for the LSRS respectively. In order to obtain vibration data at the steering wheel, a vibration output channel was introduced at the steering wheel. This output channel gives the vibration results corresponding to the input given.

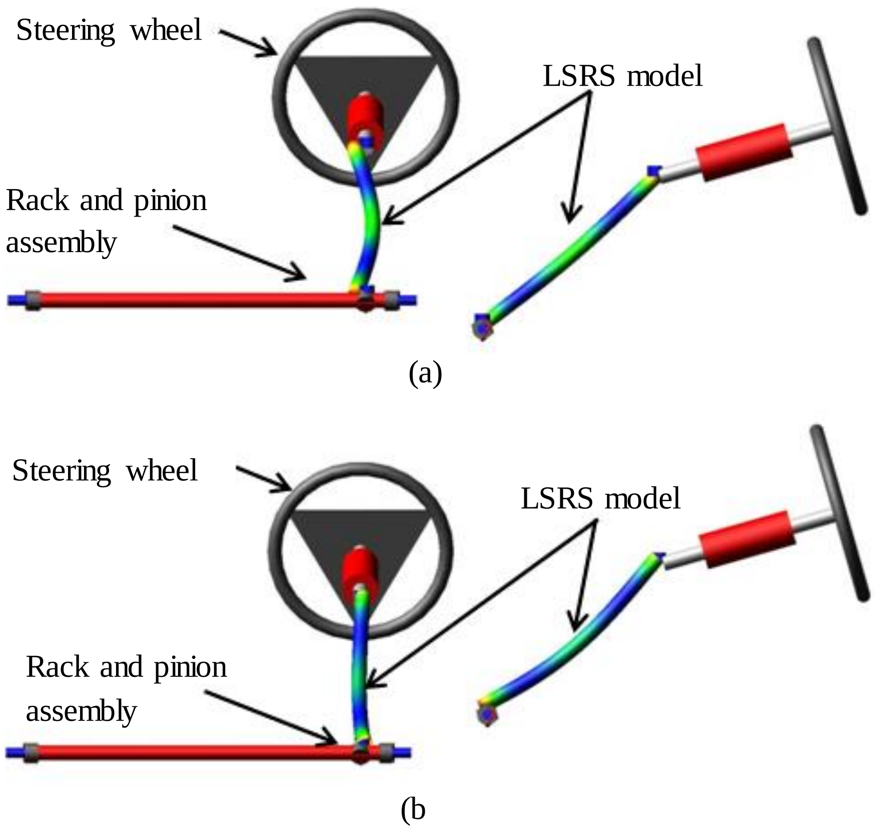

Figure 4. (a) Mode 7 LSRS frequency model, (b) mode 8 LSRS frequency model.

RESULTS AND DISCUSSION

In order to assess the effects of vibration on the steering wheel when LSRS is installed, two types of simulation were conducted. The first was the excitation simulation where the four-post test rigs were given an input to imitate the condition where the excitation mode was set to be a pitch movement with a magnitude of 20 mm. The inputs for each of the posts (front left, front right, rear left and rear right) are shown in Figures 5(a), 5(b), 5(c) and 5(d) respectively. The simulation was run for 10 s and the displacement results yielded due to each input are shown in Figure 6. As shown in the figures, the front and rear input are different; this is because the simulation was set to imitate a pitch movement. The front and rear input have different phases to enable the vehicle's center of gravity (CG) to shift from front to rear and vice versa. The frequency of the shifting in CG was high in order to produce the vibration that is intended to test the LSRS assembly.

Figure 7 shows the effect of shifting of the CG on the steering wheel. As observed from the figure, from the start of simulation until T=7.4 s, both steering wheels responded in much the same way. This is because both steering systems were attached to the chassis, which influenced the movement of the steering wheel. From T=7.4 s onwards, the behavior of the two steering systems started to show some differences. The conventional steering started to displace more compared to the SAS system. This is because the normal conventional steering has a rigid column which connects the rack and pinion assembly to the steering wheel. The massive vibration at the contact patch of the wheel causes the steering wheel to displace more. This result also represents the vibration that is felt by the driver at the steering wheel. On the other hand, the SAS steering system which was modeled with LSRS displaced less than the conventional steering. The flexibility of the LSRS allows the rack and pinion assembly to displace according to the input but it does not have much effect at the steering wheel.

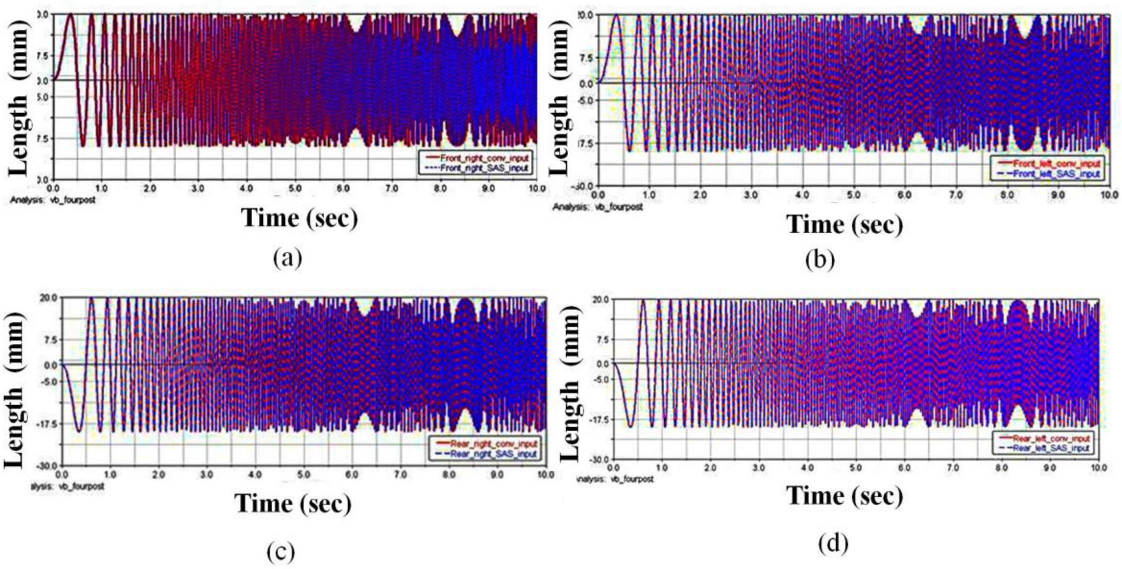

Figure 6. (a) Front right input, (b) front left input, (c) rear right input, (d) rear left input.

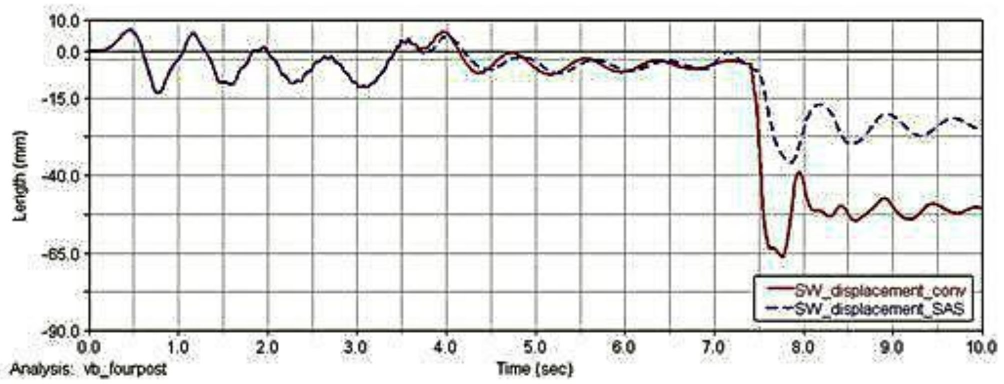

Figure 7. Displacement result of the steering wheel.

The second simulation was the vibration simulation where the four-post test rigs were given a vibration input. The input was placed at the contact patch of the wheel as well as at the wheel center. The vibration actuator for this simulation was defined as a swept sine function. The function is defined as follows:

$$f(\omega) = F \times [\cos\theta + j\sin\theta] \tag{1}$$

where $f(\omega)$ is the forcing function, F is the force magnitude and θ is the phase angle. For this simulation, the magnitude is set to 1000 N with 0° as the phase angle. The results of the vibration output and phase angle at the steering wheel and at the shaft are shown in Figures 8 and 9, respectively.

Figures 8 and 9 show the results of vibration in terms of magnitude and phase angle. The outputs were obtained from two different locations, at the steering wheel and also at the steering column for the conventional steering system. For the SAS system, the outputs are from the steering wheel and at the LSRS. From the results, there are two responses which occur at around 2.2 Hz and 72 Hz. It was observed that, at low frequency level, the LSRS yielded a lower magnitude response. This is due to the fact that the flexibility of the LSRS has introduced extra damping and additional DOF in the system. But at higher frequency, the LSRS responded more compared to the conventional steering system. These results can also be observed at the steering column under conventional steering and at LSRS with the SAS system. LSRS yielded a lower magnitude of vibration compared to the two columns in the conventional steering system. Again this proved that the flexibility of the LSRS has introduced additional damping to the system, thus reducing the vibration felt at the steering wheel.

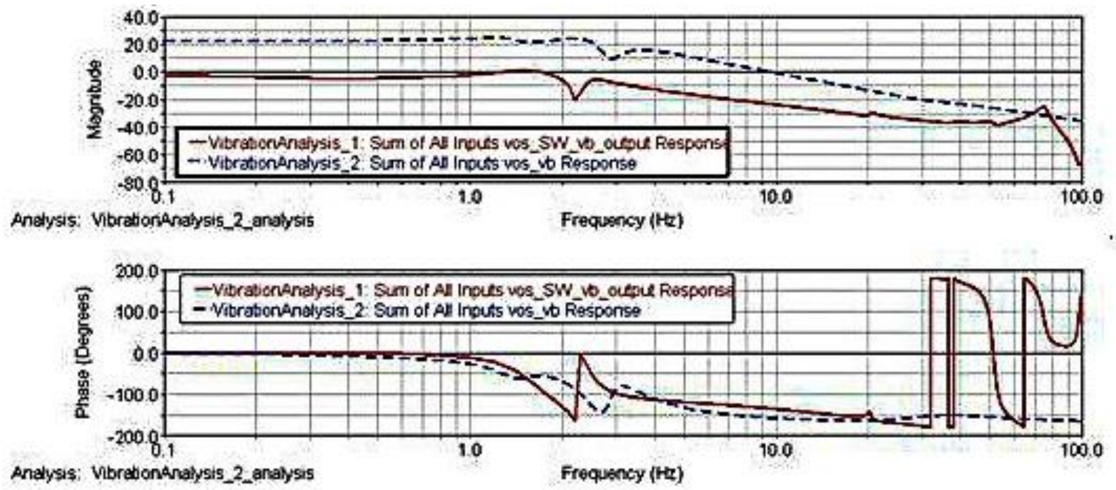

Figure 8. Magnitude and phase angle output at steering wheel.

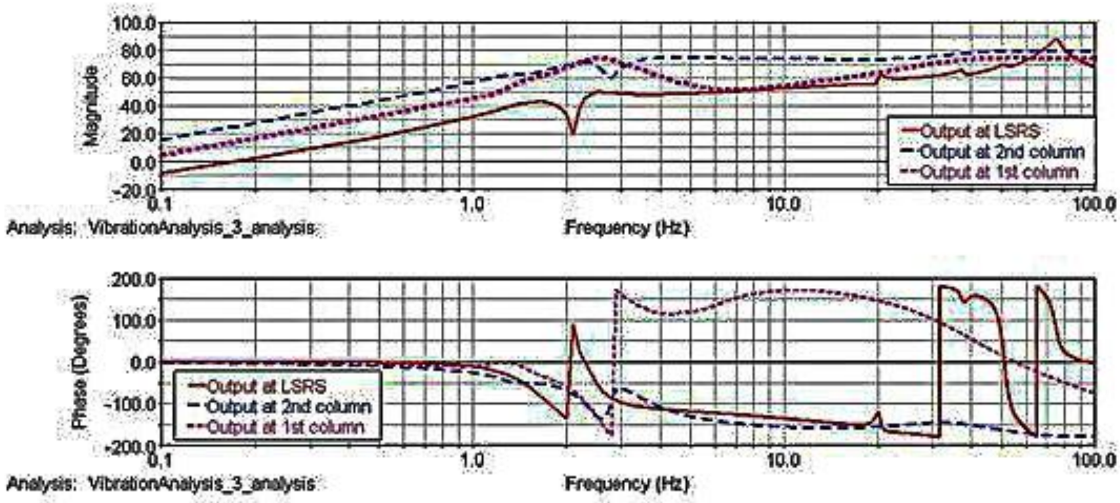

Figure 9. Magnitude and phase angle output at LSRS and steering columns.

CONCLUSIONS

Vibration at the steering wheel affects the feel of driving a vehicle. The vibration is transferred from the wheel to the rack and pinion assembly and can eventually be felt by the driver. In this research, the LSRS was used to replace the conventional steering wheel column of a normal steering system. It was found that the flexibility of the LSRS introduced extra damping to the system. It was also discovered that the LSRS was good at very low frequency and responded as expected at high frequency. Therefore it can be concluded that the LSRS used in the SAS assembly should be able to reduce some amount of vibration compared to a normal steering wheel column.

ACKNOWLEDGEMENTS

Special thanks to the Mechanical Engineering Department, University Teknologi PETRONAS, Centre of Automotive Research and Electric Mobility (CAREM) and Research and Innovation Office (RIO), UTP for the support under STIRF (0153AA-C16)

REFERENCES

[1] Gillespie TD. Fundamentals of vehicle dynamics. SAE Technical Paper; 1992.
[2] Zulkarnain N, Zamzuri H, Mazlan SA. Ride and handling analysis for an active anti-roll bar: case study on composite nonlinear control strategy. International Journal of Automotive and Mechanical Engineering. 2014;10:2122-242.
[3] Knowles D, Erjavec J. Automotive suspension and steering systems: Cengage Learning; 2002.
[4] Phaal R, Farrukh CJ, Probert DR. Technology roadmapping—a planning framework for evolution and revolution. Technological Forecasting and Social Change. 2004;71:5-26.
[5] Chang S. Implementation and control logic design of intelligent electric power steering system. World Electric Vehicle Journal. 2009: 3: 1-8.
[6] Baharom MB, Hussain K, Day AJ. Design of full electric power steering with enhanced performance over that of hydraulic power-assisted steering. Proceedings of the Institution of Mechanical Engineers, Part D: Journal of Automobile Engineering. 2013:0954407012468413.
[7] Haggag S, Alstrom D, Cetinkunt S, Egelja A. Modeling, control, and validation of an electro-hydraulic steer-by-wire system for articulated vehicle applications. IEEE/ASME Transactions on Mechatronics. 2005;10:688-92.
[8] Yih P, Gerdes JC. Modification of vehicle handling characteristics via steer-by-wire. IEEE Transactions on Control Systems Technology. 2005;13:965-76.
[9] Chang S-C. Synchronization in a steer-by-wire vehicle dynamic system. International Journal of Engineering Science. 2007;45:628-43.
[10] Xiuwei F, Li F, Feng K. Research of automotive steer-by-wire control based on integral partition pid control. IEEE 3rd International Conference on Genetic and Evolutionary Computing. 2009; 561-4.
[11] Zhai P, Du H, Li Z. Bilateral control of vehicle Steer-by-Wire system with variable gear-ratio. 8th IEEE Conference on Industrial Electronics and Applications. 2013; 811-5.

[12] Fahami SMH, Zamzuri H, Mazlan SA, Zakaria MA. Modeling and simulation of vehicle steer by wire system. IEEE Symposium on Humanities, Science and Engineering Research. 2012; 765-70.
[13] Mogi K, Sugai T, Sakurai R, Suzuki N. Development of a New steer-by-wire system. NTN Technical Review. 2011: 79:42-50.
[14] Rajamani R. Vehicle dynamics and control. Springer Science & Business Media; 2011.
[15] Black MD, Rao MD. Evaluation and reduction of steering column vibration of a rear wheel drive sedan. International Journal of Vehicle Noise and Vibration. 2004;1:122-41.
[16] Botti J, Venizelos G, Benkaza N. Optimization of power steering systems vibration reduction in passenger cars. SAE Technical Paper NO. 951253; 1995.
[17] Sahinkaya Y. A novel steering vibration stabilizer. SAE Technical Paper No. 960930; 1996.
[18] Baharom M, Hussain K, Day AJ. Design concepts and analysis of a semi-active steering system for a passenger car. Proceedings of the Institution of Mechanical Engineers, Part K: Journal of Multi-body Dynamics. 2009;223:283-92.
[19] Baharom MB. Design of a semi-active steering system for a passenger car: University of Bradford; 2008.