Acta Technica *62* No. 4B/2017, 1–10

Developing optimal suspension system of sport utility vehicle by application anti-roll bar[1]

Golamhossein Soleimani[1,3], Majid Nouri Kamari[2], Amir Afkar[2]

Abstract. Optimal suspension system has a significant impact on vehicle performance, so, enhancing optimal suspension system is one of the most efficient techniques, which could significantly improve the vehicle ride and handling properties. In the present article, a double wishbone suspension system often used in Sport Utility Vehicles (SUV) is modeled using ADAMS software. Then, performance of suspension system are optimized by developing an anti-roll bar in a way that ride comfort, handling and steerability of vehicle are improved. Then a suspension system on a vehicle model is simulated in various road conditions and steering angles in ADAMS. The findings revealed that the Anti-roll bar system by tuning the roll stiffness improves the vehicle performance.

Key words. Sport utility vehicle, handling, anti roll bar, double wishbone, vehicle lateral dynamic, ADAMS.

1. Introduction

Vehicle performance, drivability and improving handling properties of the vehicle are important issues among SUVs which can be achieved by optimum design of suspension systems and using roll controlling systems. The vehicle roll angle should be controlled in the predefined range [1–3] to enhance the stability and prevention turnover over the maneuvers. Since SUV move in rugged desert roads with a lot of roughness, designing optimal components of suspension system which can guaranty vehicle stability is vital in automotive industry. Unlike passenger vehicles where passenger's comfort is the most important issue, the main objective of suspension system's design in SUV is handling properties and appropriate ride of the vehicle in roads with rippling. Thus, double-wishbone suspension systems are used in SUV

[1]School of Automotive Engineering, Iran University of Science and Technology, Tehran, Iran

[2]Faculty of Electrical, Mechanical and Construction Engineering, Department of Automotive Engineering, Standard Research Institute (SRI), Karaj P. O. Box 31745-139, Iran

[3]Corresponding author

which provide favorable conditions in terms of handling properties in relation to other suspension types. In previous work, the optimum ride of vehicles has been tried to be obtained using geometric parameters or optimization of stiffness confident and damping of suspension system [4, 5]. Or control systems including applying active front steering, active suspension systems and direct yaw moment control systems. The previous works also have not considered the impact of geometry and suspension type in handling conditions [6, 7]. Kanarachosa and Kanarachos [8] proposed a method to design an intelligent suspension system with the objective to overcome the trade-off barrier by using the hybrid evolutionary approaches based on genetic algorithm. They tuned the suspension system to achieve optimal performance based on ride conditions. In this paper we developed an anti-roll bar mechanism and optimal suspension geometry to achieve proper handling properties and minimized roll angle and lateral acceleration to keep the stability.

2. Geometric parameters of suspension system

This article evaluates the effect of geometric parameters of heavy vehicle's suspension system which has been schematically show in Fig. 1 in handling and stability of vehicle in order to optimally design geometric parameters of vehicle's suspension system.

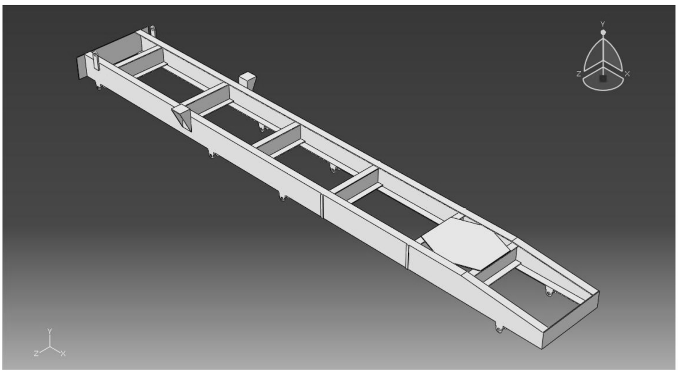

Fig. 1. Heavy tactical vehicle's chassis

The angle of Camber is one of the most important kinematic factors which has significant effect in better handling of vehicle. Camber angle is the angle of wheel's axis from the front with vertical line which is positive if it is toward inside of the car and is negative if it is toward outside of the car. This angle causes uniform pressure distribution of vehicle weight on the rubber surface. Advantage of optimum Camber is stability in driving because it increases reliance surface and lowers the center of gravity.

The important note in geometric parameters of suspension system is effectiveness and geometrical relation of each of the parameters with the camber angle. In other words, changes of Camber angle affect each of the geometric parameters of the suspension and dynamic system of vehicle (Lateral forces exerted on the tire). It has been shown for step handling input that forces created in tire due to Camber angles and handling can have a detrimental effect on vehicle stability. Also, minimizing Camber changes increases the reliance of tires and road, improves vehicle stability, improves control and ride and reduces tires wear out. For this purpose, we tried to minimize Camber angle changes to optimize geometric parameters of suspension system. These changes can be due to vertical displacement and twisting of vehicle's body. For this purpose, double-wishbone suspension system used in SUV has been initially modeled in Adams software in this article and then mechanism and geometry of suspension system has been optimized by evaluation of geometric parameters and angles of wheel and suspension system in different vehicle maneuvers caused by vertical displacement (roughness of the road) and vehicle's twist in a way that stability and handling of vehicle increases in different conditions. Figure 2 shows changes of camber angle in two modes of positive and negative for the sample suspension system.

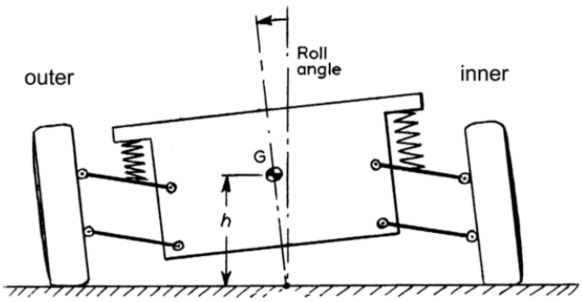

Fig. 2. Vehicle body while rolling

3. Geometric modeling of suspension system

3.1. Force distribution

Side view front wheel SLA front suspension is illustrated in Fig. 2 and the dynamic equations are presented as follows:

$$\sum M_{\mathrm{AB}} = 0, \quad F_{\mathrm{US}} h = F_{\mathrm{B}} \Rightarrow F_{\mathrm{US}} = F_{\mathrm{B}} \frac{a}{h}\,,$$

$$\sum F_x = 0, \quad F_{\mathrm{US}} - F_{\mathrm{LS}} + F\mathrm{B} = 0\,,$$

$$F_{\mathrm{LS}} = F_{\mathrm{B}} \left(1 + \frac{a}{h}\right)\,. \tag{1}$$

Also, the dynamic model of vehicle for longitudinal force, lateral force, and total torques applied to vehicle in x and z directions are presented as follows [9]:

$$\sum F_x = F_{xfl} + F_{xfr} + F_{xrl} + F_{xrr}\,, \tag{2}$$

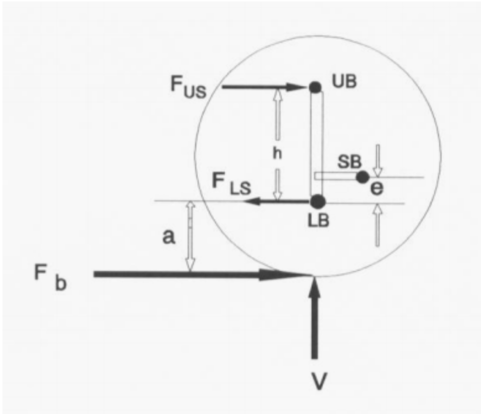

Fig. 3. Load distribution

$$\sum F_y = F_{yfl} + F_{yrl} + F_{yrl} + F_{yrr}\,, \tag{3}$$

$$\sum M_z = a(F_{yfl} + F_{yfr}) - b(F_{yrl} + F_{yrr})$$

$$+\frac{T}{2}\left[(F_{xfl} + F_{xrl}) - (F_{xfr} + F_{xrr})\right] + \sum_{i=1}^{4} M_{zi}\,, \tag{4}$$

$$\sum M_x = -m_s h(\dot{v} + ru) + (m_s gh - k_\Phi)\Phi - C_\Phi \dot{\Phi}\,. \tag{5}$$

In the above equations, F and M present force and momentum acting on the tire, respectively, T, a, and b are vehicle track and distance of the center of gravity to front and rear axles, respectively, C_Φ and k_Φ are damping and stiffness ratios of vehicle roll direction, and m_{s} is the vehicle sprung mass.

In the investigated case, $T = 1.5\,\mathrm{m}$, $a = 1.2\,\mathrm{m}$, $b = 1.4\,\mathrm{m}$, $C_\Phi = 150000\,\mathrm{N\,s/rad}$, $k_\Phi = 40000\,\mathrm{N/rad}$, and $m_{\mathrm{s}} = 1800\,\mathrm{kg}$.

3.2. Anti-roll bar design

Anti-roll bar is a part of suspension system of majority of light and heavy vehicles which assist in reduction of roll angle over the rapid maneuvers or crossing the path with roughness. Anti-roll bar links two wheels of axel (left/right) through short lever arms which are connected to a coil-spring. In fact, anti-roll bar increases hardness of suspension system and its resistance to roll in turns independent from its spring rate.

Harder bar requires more power to move left and right wheels relative to each other. This factor increases the amount of power required to roll the body and is given as

$$Q = \frac{10^4 T^2 K^2 d^4}{R^2 L}\,. \tag{6}$$

In order to design anti-roll bar, we will consider torsion equation of vehicle based on equation (6)

$$m_s gh \sin \Phi + m_s a_y h \cos \Phi = \left[\sum_{r,f} \frac{T^2}{2} k + \sum_{r,f} k_{t\mathrm{ARB}} \right] \Phi \,, \tag{7}$$

where m_s is the mass of suspension (kg), g is the gravitational acceleration ($9.81\,\mathrm{m/s^2}$), h denotes the height of the center of gravity of the vehicle (m), Φ stands for the roll angle, a_y represents the lateral acceleration of the vehicle ($\mathrm{m/s^2}$), T is the transverse distance of springs (m), r and f denote the front and rear indexes, k denotes the spring vertical stiffness (N/m) and $k_{t\mathrm{ARB}}$ is the torsional stiffness of anti-roll bar. The term inside of the bracket indicates car's torsional stiffness in equation (7).

4. Results

4.1. The results of the anti-roll bar design

In order to evaluate the effect of adding anti-roll bar to SUV, this vehicle has been modeled in ADAMS software and has been placed under handling maneuvers.

4.1.1. Handling maneuver. The vehicle performs a double redirect maneuver at a speed of 70 km/h in this maneuver results for without anti-roll bar (sus1), with anti-roll bar (sus2) and desired (sus3) are presented in Figs. 4 and 5 for lateral acceleration and velocity, respectively. Also, body roll angle with and without anti roll-bar are illustrated in Figs. 6 and 7.

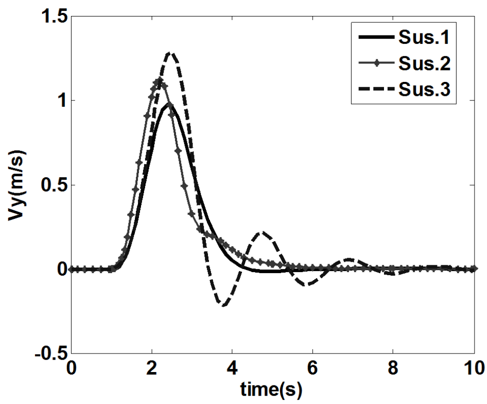

Fig. 4. Lateral velocity

As it can be observed, slipping of tires as well as the amount of body roll are reduced by adding anti-roll bar. This means that the designed anti-roll bar has improved ride behavior of the vehicle. Improved vehicle's handling and stability

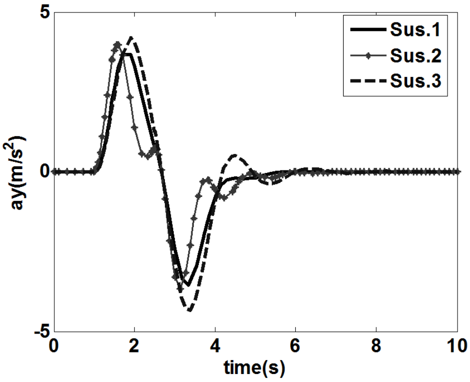

Fig. 5. Lateral acceleration

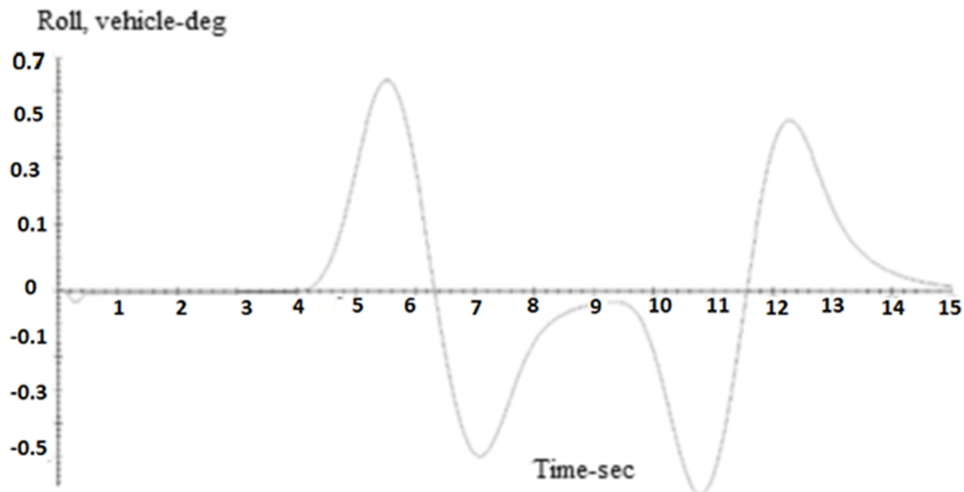

Fig. 6. Body roll angle without anti-roll bar

mean better and higher security for the vehicle and especially the sensitive load which is being carried.

4.1.2. Vehicle's handling maneuver. In this maneuver, the vehicle moves at the speed of 60 km/h on a rugged road. As it can be observed, adding the designed anti-roll bar has not had negative effect on roll function of the vehicle, thus it can be seen that vehicle's handling has not been changed along with increasing vehicle stability, and ultimately vehicle dynamic behavior has been improved.

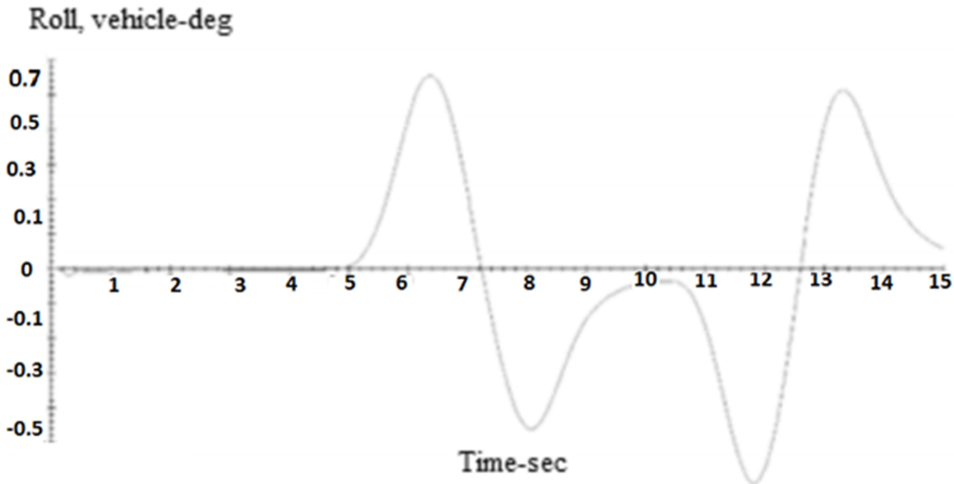

Fig. 7. Body roll angle with anti-roll bar

4.2. The results of designing torsion bar for independent axis

Modeling coil-spring of 3rd and 4th axis of super heavy vehicle was carried out in ADAMS software. Coil springs have been simulated in ADAMS dynamics software in this section and then this super heavy vehicle will be tested with new springs in ride and handling maneuver.

It can be observed based on diagrams of Figs. 8 and 9 that even though amounts of Camber angle caused by displacement and twists in the positive direction of the coordinates of the vehicle are higher than negative direction, the changes in camber angle are relatively symmetric. Changes of camber angle increase by increasing angle of roll or bump height which shows tendency of wheel toward outside of the vehicle and its instability but it can be observed that these Camber changes are lower for optimum suspension system compared to camber changes in non-optimum suspension system which shows better stability of the vehicle with optimized double-wishbone suspension. In this maneuver similar to turning maneuver, optimized suspension system has been able to pass the road with the least lateral deviation in addition to preserving the stability of the vehicle by adding anti-roll bar and torsion bar.

5. Conclusion

In this article, modeling of heavy vehicle's suspension system has been done for SUV in ADAMS software. Then we tried to optimize geometric characteristics of suspension system using geometric equations governing the suspension system with the aim of minimizing Camber angle changes by adding anti-roll bar and optimized torsion bar. Then sensitivity analysis and changes in suspension geometry parame-

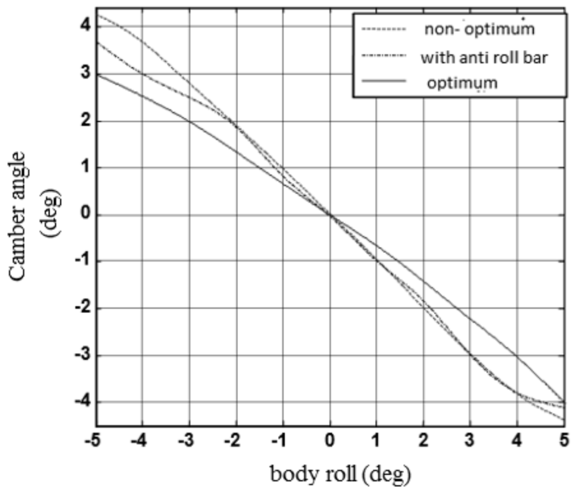

Fig. 8. Changes of Camber angle due to bump

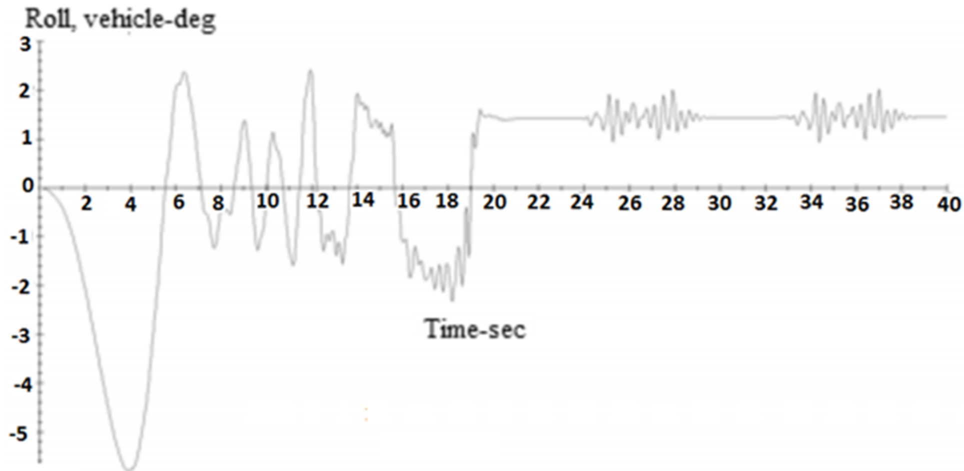

Fig. 9. Body roll angle

ters caused by inputs of bump and vehicle rolls were compared for three modes of non-optimal, optimal with anti-roll bar and optimal with torsion bar. The results show that the maximum camber angle and its range are reduced with optimizing the geometrical parameters. It can also be observed with examining the suspension system under transient conditions that camber angle changes in the steady state have fluctuations in non-optimized mode which can change the forces exerted on tire and reduce vehicle handling. But these fluctuations have fallen sharply by optimizing the suspension system and system reaches steady-state faster. In the next step, Simulation of movement of vehicle during two standard maneuvers of turning and changing direction has been carried out for lateral dynamic variables of vehicle with a comprehensive modeling of SUV in ADAMS software to evaluate conditions to control the direction, Handling, ride and stability of vehicle. Results of the simulation show that the type of suspension system and geometric parameters of it have significant effect on handling, stability and prevention of overturning of vehicle. In conclusion we found that the optimal design of suspension with anti-roll bar for SUVs significantly can improve the vehicle stability and maneuverability over the rough maneuvers.

References

[1] D. A. Mántaras, P. Luque, C. Vera: *Development and validation of a three-dimensional kinematic model for the McPherson steering and suspension mechanisms.* Journal of Mechanism and Machine Theory *39* (2004), No. 6, 603–619.

[2] S. A. Chen, J. C. Wang, M. Yao, Y. B. Kim: *Improved optimal sliding mode control for a non-linear vehicle active suspension system.* Journal of Sound and Vibration *395* (2017), 1–25.

[3] H. Habibi, K. H. Shirazi, M. Shishesaz: *Roll steer minimization of McPherson-strut suspension system using genetic algorithm method.* Mechanism and Machine Theory *43* (2008), No. 1, 57–67.

[4] B. Mashadi, M. Mahmoodi-K, A. Kakaee, R. Hosseini: *Vehicle path following control in the presence of driver inputs.* Proceedings of the Institution of Mechanical Engineers, Part K: Journal of Multi-body Dynamics *227* (2013), No. 2, 115–132.

[5] O. Mokhiamar, M. Abe: *Active wheel steering and yaw moment control combination to maximize stability as well as vehicle responsiveness during quick lane change for active vehicle handling safety*, Proceedings of the Institution of Mechanical Engineers, Part D: Journal of Automobile Engineering *216* (2002), No. 2, 115–124.

[6] P. S. Els, N. J. Theron, P. E. Uys, M. J. Thoresson: *The ride comfort vs. handling compromise for off-road vehicles.* Journal of Terramechanics *44* (2007), No. 4, 303–317.

[7] Y. Pourasad, M. Mahmoodi-K, M. Oveisi: *Design of an optimal active stabilizer mechanism for enhancing vehicle rolling resistance.* Journal of Central South University *23* (2016), No. 5, 1142–1151.

[8] S. Kanarachosa, A. Kanarachos: *Intelligent road adaptive suspension system design using an experts' based hybrid genetic algorithm.* Expert Systems with Applications *42* (2015), No. 21, 8232–8242.

[9] M. Mirzaei: *A new strategy for minimum usage of external yaw moment in vehicle dynamic control system.* Transportation Research Part C: Emerging Technologies *18* (2010), No. 2, 213–224.

Received October 31, 2017