2018 3rd International Electrical Engineering Conference (IEEC 2018)
Feb, 2018 at IEP Centre, Karachi, Pakistan

Design and Analysis of Anti-Lock Braking System

Mansaf Ali Abro[1] ,Shoaib Shaikh[2], Ali Asghar[3], Syed Nadeem Mian[4] and
Imtiaz Hussain Kalwar[5*]

[1-4] Department of Energy Engineering, Hamdard University main campus Karachi, Pakistan
(Mansaf.ali@hamdard.edu.pk)

[5] Department of Electrical Engineering, DHA Suffa University Karachi, Pakistan
(Imtiaz.Kalwar@gmail.com) *

Abstract: Fatal road accidents are increasing day by day. The life of people while driving on roads is becoming dangerous. Researchers have come to know that accidents occur due human error but majorly due to mechanical f ault. This research paper primarily focuses on development of such a mechanical system which can control vehicl e automatically and save human lives. Therefore development of such a system is depicted in this research paper. Initially the system model is developed using Simulink in Mat lab and results are obtained in last. The modeling is such that the individual components of model are formed from the equations which are shown and discussed se parately. The components of model include (tire model, quarter car model, brake actuator and PI controller). Furt hermore the model shows robustness of controller where it is implemented in continuous time. In continuous time it behaves robustly to control vehicle when excessive slip occurs. The results obtained in this research work are v alidated with published work. However, the system can be adopted rudimentary for Anti-lock braking system (AB S) and anti-slip regulatory system (ASR). Sometimes driving the vehicle on slippery or icy surfaces causes it to get out of control. Therefore major focus of this research is to get vehicle under control when slip occurs.

Keywords: Anti-lock braking system, slip, PI controller, Quarter car model

I. INTRODUCTION

Deadly accidents occurs on roads frequently now-a-days. Research in vehicle dynamics and control engineering is getting advancement day by day. Different techniques and ways are being discovered. Among such anti-Lock Braking System (ABS) is one. It is an active system which is used to control vehicle dynamics under braking. It does it by regulating wheel longitudinal slip at optimum slip value. By doing this it gains maximum braking force. Thus it controls not only vehicle while slipping but also reduces stopping distance. It ensures directional stability and avoid vehicle to skid. Vehicles which are not equipped with ABS face locking condition when applied excessive braking. In which a tire gets locked. When tire gets locked then friction coefficient falls below sliding value. Thus the ability of vehicle to sustain side force is reduced to null. Therefore, stopping distance increases and directional vehicle while turning losses its grip. So the vehicle gets out of control and derails which cause fatal accidents [1-7]

Primary purpose of ABS is to prevent the vehicle from becoming locked during excessive braking. It does it by controlling the braking torque by varying brake pressure. The model uncertainties and non-linearity make it difficult to develop a control law for ABS. Model un certainties and nonlinearity contain variation in road conditions and vehicle parameters. It can be summarized from above discussion that there is a need to design a controller which can control vehicle when excessive slip occurs. Such a controller which can deal with non-linearity. Therefore a wheel slip controller must be designed with increased robustness. Moreover that controller can be designed by nonlinear control law. In this regard slide mode controller has been applied to deal with nonlinearities for ABS system [1, 8-17] but there is a drawback using slide mode controller for ABS that it generates chattering phenomenon. Different methods have been adopted to reduce chattering such as in [10, 16, 18]. Scientists and researchers have done a noteworthy work in the design of ABS system. The following are most important methods which are used for designing ABS system. [10] worked on ABS system and designed a slide mode controller. Again the chattering phenomenon was observed. Thus he used integrated switching surface method in place of sign function to reduce chattering. Combine effect of slide mode and fuzzy logic controller is observed in [13]. In [16] slide mode controller was used to obtain slip at its optimum value. Furthermore, PI controller was used with switching surface method in place of sign function to minimize the chattering. Another work was performed using slide mode controller and friction force observer. The observer was introduced to find the optimal value of longitudinal slip [9]. Researchers in [19] used Fuzzy controller to track the optimal value of slip. Moreover, the required value of slip was obtained from Pacejka formula. The four cases were generated which showed vehicle behavior by varying torque.

In this research paper a novel method has been incorporated. The introduced method in this research paper contains system modelling and dynamics of vehicle body. Furthermore tire model, actuator model and imposed simple Pi controller allowed us to control slip when excessive slip occurs. Moreover three cases generated in this research work are when driving the vehicle on three types of surfaces such as concrete/dry asphalt, snowy and ice surface. Another novelty of this research is that we have used here standard Paceijka magic tire formula. By doing this our system has behaved comprehensively and results confirm the status of our research.

II. THE QUARTER CAR MODEL

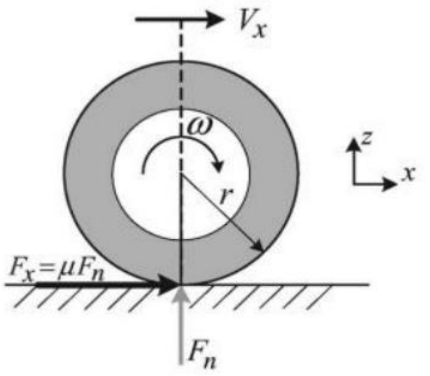

Figure 1. One Wheel Free Body Diagram [20]

Quarter Car model can give a better understanding of ABS control system. The model free body diagram of one wheel is shown in figure 1. It is assumed that wheel of model is attached to a mass m. Wheel moves due to inertia of the mass (m). The velocity of the wheel is linear due to inertia. Fx is the tire reaction force. It is generated because of interaction of tire surface with the road surface. As shown by figure 1 (ω) is the rolling motion of the wheel or it is termed as angular velocity. Normally angular velocity is by product of Torque. The torque is the generated by the reaction force of tire [21, 22].
Mathematical Equations:

$$m\dot{v} = -Fx \quad (1)$$

$$J\dot{\omega} = rFx - Tb\ sign\ (\omega) \quad (2)$$

Where

v	Longitudinal speed at which the car travels
ω	Angular speed of the wheel
Fz	Vertical force
Fx	Tire frictional force
Tb	Braking torque
r	Wheel radius
J	Wheel inertia

Further more

$$Fx = Fz.\mu(\lambda, \mu H, \alpha) \quad (3)$$

Where μ is the friction co-efficient which is nonlinear function of the slip.

λ	Slip of tyre
μH	Interaction / frictional coefficient between tyre and road
α	Slip angle of the wheel

Moreover

$$\lambda = (v - \omega r)/v \quad (4)$$

Where λ defines the difference between horizontal velocity (v) and wheel parameter (ωr).

If $\lambda = 0$ then there will be no frictional force (Fx). And body will execute free motion. If $\lambda = 1$ then the wheel is said to be locked. And the body will be affected by frictional force (Fx). Eventually the vehicle executes no motion or it will be stand still. Thus frictional co-efficient μH and the shape of friction curve μx can vary a wide range. The variations in curve depend upon the road conditions (dry or wet). The other factors which also affect the curve are the surfaces on which vehicle operates such as (icy, snowy, gravel, asphalt etc.), slip angle of wheel which can change according to the steering of the vehicle and type of tire. In this research paper dynamics of the system are analyzed by changing the parameters of equations (1) and (2). And also angular speed ω of the wheel which is replaced by the slip (λ). It is also assumed here that $\omega \geq 0, v \geq 0$ and $-1 < \lambda < 1$.

The Quarter car model equation is given in [23] as:

$$\mu x = a(1 - e^{-b\lambda} - c\lambda) \quad (5)$$

III. THE TIRE MODEL

The novelty of this research is that we have used Paceijka Magic Formula. The Pacejka Magic formula is the standard formula to tire modeling [10, 16, 18]. The standard Pacejka magic formula normally gives the longitudinal frictional co-efficient

$$\mu x = a(1 - e^{-b\lambda} - c\lambda). \quad (6)$$

Where λ is the wheel slip. The coefficients (a, b, c) in this equation change according to the road surface. The parameters are defined in [20]. The parameters are also given in table form. On the basis of these parameters the behavior of the system is analyzed. In this research paper three surfaces are taken such as dry asphalt/concrete, snow and ice.

Table 2 Tire-Road Friction Parameters.

Surface Conditions	C1	C2	C3	C4
Dry Asphalt	1.029	17.16	0.523	0.03
Concrete	1.197	25.168	0.5373	0.03
Snow	0.1946	94.129	0.0646	0.03
Ice	0.05	306.39	0	0.03

Where
C1 = Maximum value of friction curve.
C2 = Friction Curve Shape.
C3 = Friction curve difference between the maximum value and value at $\lambda = 1$.
C4 = wetness character value.

IV. OVERVIEW OF THE COMPLETE MODEL

The control loop used in this research paper has been dep icted in Figure 2. The loop consists of (Controller, actuat or and quarter car model). Furthermore, system model is in feed forward path. The input of the control system is slip. The calculated wheel slip from Paceijka Magic formula (after controlled mechanism) is fed back and compared to desired value of slip. The desired slip obtain ed here is the error which is fed into the controller.

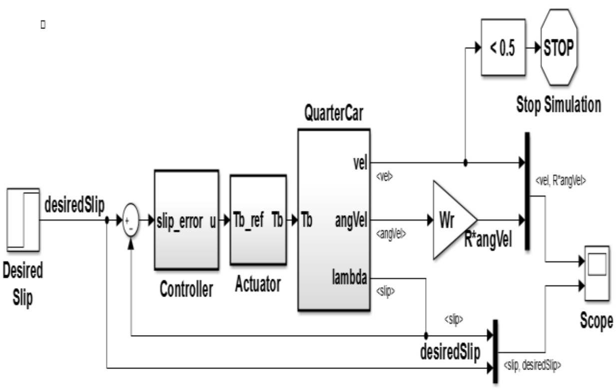

Fig .2 Simulink Model of Quarter Car Wheel Slip Control Loop.

V. SIMULATION RESULTS

Case: 1 when a vehicle drives on a concrete/ dry asphalt surface.

Figure 3 (i) shows two lines. Yellow line shows vehicles longitudinal velocity and blue line shows vehicles linear velocity. The linear velocity can be obtained by multiplying radius of the tyre with the rotational motion. longitudinal and linear velocities are same for some distance. But after some distance vehicle observes a slip of 10 %. The Unusual behavior of vehicle when slip occurs is shown in fig 3 (ii). Then ABS becomes active and did not allow vehicle to lock. Thus, it controls the vehicle until it comes to rest.

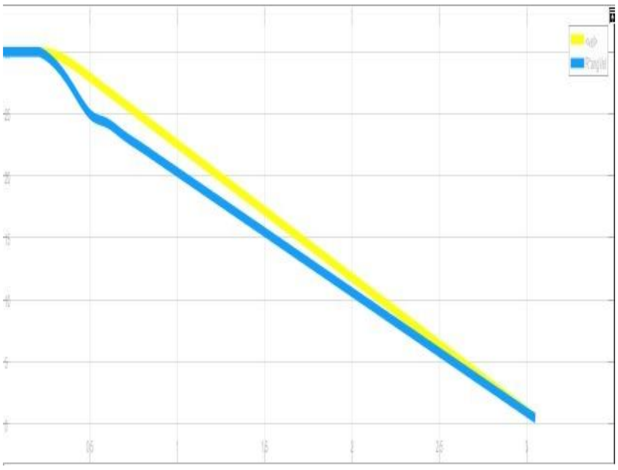

Figure 3 (i) when vehicle runs on concrete/ dry asphalt.

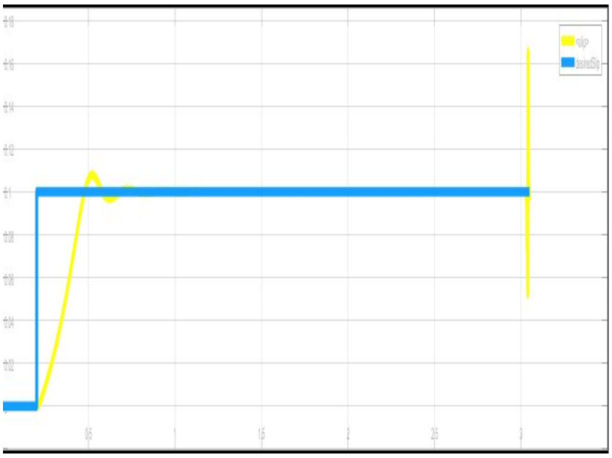

Figure 3 (ii) shows slip vs. desired slip graph

Case: 2 when a vehicle drives on a snowy surface.

Figure 4 (i) shows two lines. Yellow line shows vehicles longitudinal velocity and blue line shows vehicles linear velocity. Considering wheels motion the longitudinal velocity remains same throughout the motion. But the linear velocity which is shown by blue in figure 4(i) shown drastic changes. But our employed ABS system has performed and it has not allowed the vehicle to lock.

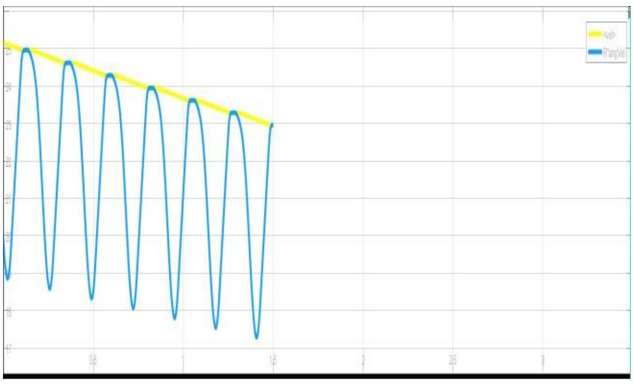

Figure 4 (i) Relationship between linear velocity and longitudinal velocity when vehicle runs on snowy surface.

Figure 4 (ii) shows two lines. Yellow line shows slip. The obtained slip is unusual. This unusual slip gives the idea of surface. Because this time the vehicle is driven on snowy surface thus graph obtained is unusual. It is due to the employed ABS system vehicles did not lock and comes to rest after a period of 1.5 seconds.

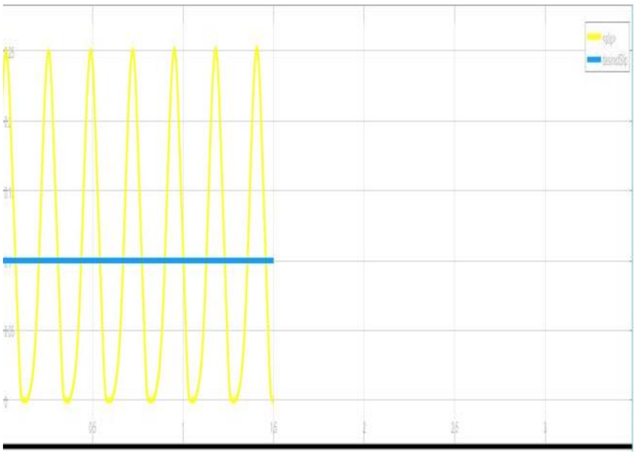

Figure 4 (ii) shows wheel slip angle when vehicle runs on snowy surface.

Case: 3 when a vehicle drives on a icy surface.

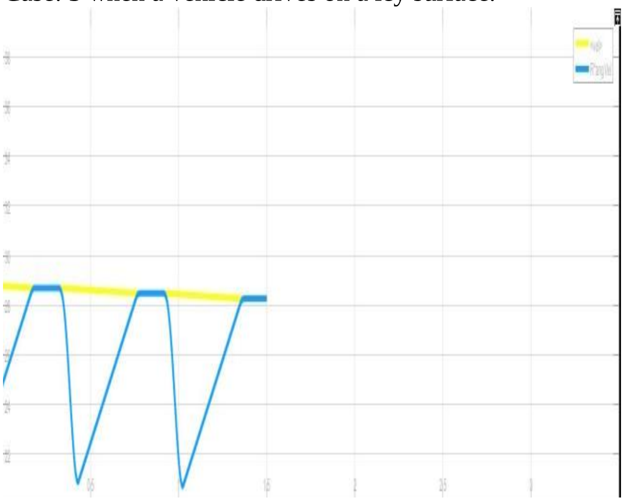

Figure 5 (i) shows longitudinal velocity and linear velocity.

When vehicle runs on icy surface. The employed ABS system has worked comprehensively to control vehicle.

Figure 5 (ii) shows two lines. In this case the vehicle is driven on icy surface. As shown by figure 5 (ii) the yellow line shows slip. The obtained slip is irregular. This irregular slip gives the idea of surface which is highly nonlinear. Due to ABS vehicle comes to rest after a period of 1.5 seconds.

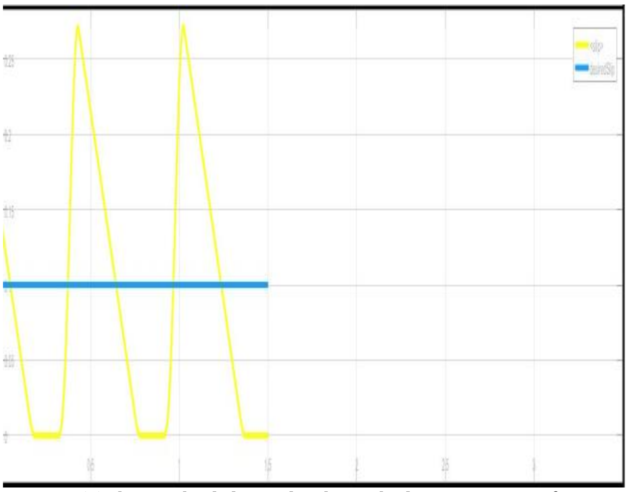

Figure 5 (ii) shows wheel slip angle when vehicle runs on icy surface.

VI CONCLUSION

The crux of the matter is that the problem area as slip was defined. It is due to the slip the wheels gets derailed. As noted earlier that about 90 percent accidents are occurring due to mechanical fault. Which allowed researchers to work for such a system which can control vehicle automatically. Thus this research paper depicts a novel approach for the design of such a system.it was shown that by incorporating Anti-lock braking in vehicles can prevent locking mode and avoid slip. In this regard the system model was designed on which basis mathematical equations were driven then those equations were incorporated on Simulink. Furthermore the system model is run and results are simulated in three different cases. The three cases generated in this research work are when driving the vehicle n three types of surfaces such as concrete/dry asphalt, snowy and ice surface. Another novelty of this research is we have used here standard Pacejka magic formula. By doing this our system has behaved comprehensively and results confirms the status of our designed ABS system.

REFERENCES

1. Mirzaeinejad, H. and M. Mirzaei, *A novel method for non-linear control of wheel slip in anti-lock braking systems.* Control Engineering Practice, 2010. **18**(8): p. 918-926.
2. Wong, J. and C. Chiang, *A general theory for skid steering of tracked vehicles on firm ground.* Proceedings of the Institution of Mechanical Engineers, Part D: Journal of Automobile Engineering, 2001. **215**(3): p. 343-355.
3. Radac, M.-B. and R.-E. Precup, *Data-driven model-free slip control of anti-lock braking systems using reinforcement Q-learning.* Neurocomputing, 2018. **275**: p. 317-329.
4. Batyoha, D. and S. Kirichenko, *Anti-lock braking system*. 2015, Sumy State University.

5. Liu, T., et al., *Anti-Lock Braking System Control Design on An Integrated-Electro-Hydraulic Braking System.* SAE International Journal of Vehicle Dynamics, Stability, and NVH, 2017. **1**(2017-01-1578): p. 298-306.
6. O'meachair, D. and M. Crumpton, *Adaptive braking system and method*. 2017, Google Patents.
7. Perić, S.L., et al., *Quasi-sliding mode control with orthogonal endocrine neural network-based estimator applied in anti-lock braking system.* IEEE/ASME Transactions on Mechatronics, 2016. **21**(2): p. 754-764.
8. Buckholtz, K.R., *Reference input wheel slip tracking using sliding mode control*. 2002, SAE Technical Paper.
9. Drakunov, S., et al., *ABS control using optimum search via sliding modes.* IEEE Transactions on Control Systems Technology, 1995. **3**(1): p. 79-85.
10. Harifi, A., et al., *Designing a sliding mode controller for slip control of antilock brake systems.* Transportation research part C: emerging technologies, 2008. **16**(6): p. 731-741.
11. Kazemi, R., B. Hamedi, and B. Javadi, *A new sliding mode controller for four-wheel anti-lock braking system (ABS)*. 2000, SAE Technical Paper.
12. Lee, Y. and S.H. Zak, *Designing a genetic neural fuzzy antilock-brake-system controller.* IEEE Transactions on evolutionary computation, 2002. **6**(2): p. 198-211.
13. Lin, C.-M. and C.-F. Hsu, *Self-learning fuzzy sliding-mode control for antilock braking systems.* IEEE Transactions on Control Systems Technology, 2003. **11**(2): p. 273-278.
14. Park, E.J., et al., *A performance evaluation of an automotive magnetorheological brake design with a sliding mode controller.* Mechatronics, 2006. **16**(7): p. 405-416.
15. Song, J., H. Kim, and K. Boo, *A study on an anti-lock braking system controller and rear-wheel controller to enhance vehicle lateral stability.* Proceedings of the Institution of Mechanical Engineers, Part D: Journal of Automobile Engineering, 2007. **221**(7): p. 777-787.
16. Unsal, C. and P. Kachroo, *Sliding mode measurement feedback control for antilock braking systems.* IEEE Transactions on Control Systems Technology, 1999. **7**(2): p. 271-281.
17. Zheng, S., et al., *Controller design for vehicle stability enhancement.* Control Engineering Practice, 2006. **14**(12): p. 1413-1421.
18. Slotine, J. and W. Li, *Applied Nonlinear Control, Englewood Cliffs, NJ: PreticeYHall*. 1991, Inc.
19. Glumov, V.M., I.N. Krutova, and V.M.o. Sukhanov, *Fuzzy logic-based adaptive control system for in-orbit assembly of large space structures.* Automation and remote control, 2004. **65**(10): p. 1618-1634.
20. Elmas, C., U. Güvenç, and M. Doğan, *Tire-Road Friction Coefficient Estimation and Experimental Setup Design of Electric Vehicle.* 2015.
21. Johansen, T.A., et al. *Hybrid control strategies in ABS*. in *American Control Conference, 2001. Proceedings of the 2001*. 2001. IEEE.
22. Canudas-de-Wit, C., et al., *Dynamic friction models for road/tire longitudinal interaction.* Vehicle System Dynamics, 2003. **39**(3): p. 189-226.
23. Emheisen, A.A.A., et al., *Car Wheel slip Modelling, Simulation, and Control using Quarter Car Model.*