Modelling and Simulation of Anti-lock Braking System

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***Abstract*— Anti-lock braking system (ABS) is an automobile safety system that allows the wheels on a motor vehicle to maintain tractive contact with the road surface according to driver inputs while braking, preventing the wheels from locking up and avoiding uncontrolled skidding. The dynamics of the controller needed for antilock braking system depends on various factors. The vehicle model often is in nonlinear form. Controller needs to provide a controlled torque necessary to maintain optimum value of the wheel slip ratio. The slip ratio is represented in terms of vehicle speed and wheel rotation.**

In this research study of Matlab ABS model developed for single wheel is carried out and results are obtained for the same. To obtain the complete four wheel simulation CARSIM simulation software is used. The complete ABS model is developed for the hatchback and van segments car and results of both the simulation softwares are compared.

***Index Terms*— ABS, Matlab , CARSIM**

I. INTRODUCTION

Highlight a Antilock braking system (ABS) avoids brakes from locking under hard braking condition. Under typical braking conditions the driver has the control over the brakes. On the other hand, during extreme braking or on icy roadways, when wheels tends to approach the lockup condition, the ABS module takes control. ABS varies the brake line pressure irrespective of the force applied on pedal. This is done to bring the wheel speed to the predefined range which is very important for efficient braking. An ABS comprises of wheel velocity sensor, modulator, and a control unit. The ABS has a closed loop system that adjusts the brake force according to the wheel deceleration and rotational speed of wheel to keep the controlled wheel from locking. The whole ABS module close down when the vehicle pace is beneath a preset value. The wheel speed sensor present in the ABS constantly checks for any abnormalities.

Simulation of any physical system plays an important role in analyzing the behavior of the system under certain applied conditions. Simulation is the imitation of the operation of a real-world process or system over time. It is used to model, analyze, and simulate dynamic systems using block diagrams. This paper focuses on the development and simulation of the ABS model in the MATLAB and CARSIM simulation softwares and comparison of the results obtained from both the softwares. Several papers described the methodology for the ABS system or slip control system simulation. Vehicle slip controller by means of antilock braking system with Can Bus and a simulation in Matlab is proposed by Premnath Srikanthan et al in [1] and discussed further as ABS (Antilock Braking System) which is programmed and simulated in MATLAB (Matrix Laboratory), the most significantly used software which is implemented in real time through CAN (Controller Area Network) bus. CAN bus is used as interface between the controller and the software has the ability to accept many possible inputs and gives out many possible outputs. The simulations and programming using MATLAB and CAN bus acts as the ABS in order to bring the wheel speed and the vehicle speed to a relative slip of a standard 0.2-1.0.The authors have obtained the single wheel simulation and results are obtained in terms of slip, vehicle and wheel speed. An Antilock-Braking Systems (ABS) Control: A Technical Review is proposed by Ayman A. Aly El-Shafei Zeidan et al [2]. The review of the methods used in the design of ABS systems is done. Authors have mentioned the Different control methods for ABS. The authors have developed the fuzzy control based ABS model. The model is developed in this research by considering specific road conditions. Nowadays integrated software approached is developed for simulation of any physical system to obtain the more accurate results. Co-simulation of full vehicle model in Adams and anti-lock brake system model in Simulink is proposed by Tobias Eriksson [3]. Author have proposed the Modelling of the measurement vehicle and simulations with the simplified ABS model is done. The full vehicle Adams model of the vehicle is integrated with a Simulink model of the ABS developed by the brake system supplier. The vehicle model used for the simulation is VOLVO V40 vehicle. The Adams software is integrated with the ABS Matlab model to obtain the complete vehicle simulation. The problem faced by the author for during simulation is the software compatibility issue with the computer. Various methods are proposed to forecast the wheel slip for Antilock Braking System. A Dynamic Method to Forecast the Wheel Slip for Antilock Braking System and Its Experimental Evaluation is proposed by Yesim Oniz et al [4]. This paper proposed the integration of gray system theory and sliding-mode control. The prediction capabilities of the former and the robustness of the latter are combined to regulate optimal wheel slip depending on the vehicle forward velocity. The design approach described is novel, considering that a point, rather than a line, is used as the sliding control surface. The control algorithm is derived and subsequently tested on a quarter vehicle model. The several control methods have been derived for anti-lock braking system. Simulated and experimental study of antilock braking system using grey sliding mode control is proposed by Yesim Oniz et al [5]. Authors have proposed a grey sliding mode controller to track the reference wheel slip. The grey system theory, which has a certain prediction capability, offers an alternative approach to conventional control methods. The proposed controller predicts the upcoming values of wheel slip, and takes the necessary action to

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maintain the wheel slip at the desired value. The algorithm is applied to a quarter vehicle model, and it is verified through simulations indicating fast convergence and good performance of the designed controller. Results of simulation are validated on real time applications using a laboratory experimental setup. The control logic used to control ABS system can depend upon the cost of the overall system and also the accuracy that is to be obtained from the system. Antilock-Braking System Using Fuzzy Logic is proposed by Subbulakshmi. Author have proposed a new way to interface the concept of FUZZY LOGIC and ABS system used (mainly in transportation and motors) and tests on an experimental car with antilock-braking system (ABS) and vehicle speed estimation using fuzzy logic. The control philosophy takes into consideration wheel acceleration as well as wheel slip in order to recognize blocking tendencies. The knowledge of the actual vehicle velocity is necessary to calculate wheel slips. This is done by means of a fuzzy estimator, which weighs the inputs of a longitudinal acceleration sensor and four wheel speed sensors. If lockup tendency is detected, magnetic valves are switched to reduce brake pressure. Performance evaluation is based both on computer simulations and an experimental car.

As the currently available ABS models are developed by applying different control methods like gray system control, fuzzy control it has certain disadvantages like the model developed is only for the single wheel and simulation results are obtained for the single wheel data. Hence it is necessary to obtain the complete vehicle simulation of ABS in a way such that the complete four wheel simulation data can be obtained and accurate control over the ABS can be made possible by developing such model.

In this research first the MATLAB model of ABS is developed for the single wheel and later the complete four wheel simulation model of ABS model is developed for hatchback segment and VAN segment vehicle in CARSIM which is integrated with MATLAB and results of both the model developed are compared.

II. Methodology

A. Research Description

Matlab and CAR Sim simulation are widely used simulation software for analyzing the performance of the different components. In this research the simulation is carried out of the Anti-lock braking system by above two mentioned softwares. First the mathematical background of the ABS is studied and by applying the logic the Matlab Simulink model is developed for the same and corresponding results are obtained. Further the CAR Sim simulation model for the complete vehicle ABS is developed for hatchback and Van segment cars and model is simulated by applying certain conditions. The results are compared with the Matlab Simulink model which is developed for single wheel of the vehicle

B. Matlab Model Of ABS for Single Wheel

Modelling is the first and most vital assignment in creating a control calculation for the ABS. The ABS variation is very nonlinear and time varying. Towards the above objective, the model of an ABS has been developed in the Matlab by considering all the mathematics part involved in the calculation of vehicle speed, wheel speed, slip ratio etc. ABS model developed in Matlab is shown in the fig 1.

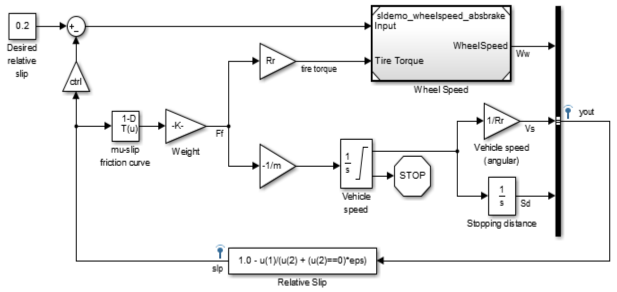

Fig 1: ABS model developed in Matlab for single wheel simulation

In the above model the desired slip ratio value is taken as 0.2. This value is compared with the slip ratio value that we get from the developed model and again the difference between these two values is supplied to the wheel speed sub system to calculate the wheel speed of vehicle. Slip ratio is the ratio of difference between vehicle speed and wheel speed to the vehicle speed. The friction coefficient (mu) between the road surface and the tire, is function of slip, known as the mu-slip curve. The mu-slip curve is developed by passing MATLAB variables into the block diagram using a Simulink lookup table. The model multiplies the friction coefficient, mu, by the weight on the wheel, W, to yield the frictional force, Ff, acting on the circumference of the tire. Ff is divided by the vehicle mass to produce the vehicle deceleration, which the model integrates to obtain vehicle velocity. Now to calcultae the wheel speed the wheel speed sub system is created which uses the bang bang controller which is on-off controller. The wheel speed subsytem is shown in the fig 2.

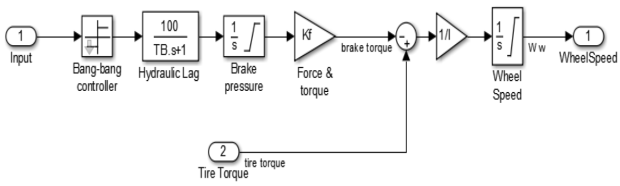

Fig 2: Wheel speed subsystem developed in Matlab for single wheel simulation

The constants values that are taken while developing the above ABS model are as follows

Input parameters for Matlab ABS model

- Gravitational constant g=32.18 ft/s^2
- Initial velocity of vehicle v_0=88 ft/s
- Wheel Radius Rr=1.25 ft
- Mass of vehicle m=50 lbs.
- Maximum Braking Torque $Tbmax$=1500 $lbf*ft$
- Hydraulic Lag TB= 0.01 s
- Moment of Inertia Jw=5 ft^4

To have a control on the rate of change of brake pressure, the mathematical model subtracts actual slip from the desired slip and feeds this value into a bang-bang control (+1 or -1, depending on the sign of the error). This on/off value passes through a first-order hydraulic lag that represents the delay associated with the hydraulic lines of the brake system. Then the model integrates the filtered rate to yield the actual brake pressure. The resulting signal is then multiplied by the piston area and radius with respect to the wheel, KI, is the brake torque applied to the wheel. The model then multiplies the frictional force on the wheel by the wheel radius (Rr) to give the acceleration torque of the road surface on the wheel. The brake torque is subtracted from the accelerating torque to give the net torque on the wheel. Net torque is divided by the wheel rotational inertia, I which yields the wheel acceleration, which is then integrated to provide wheel velocity. In order to keep the wheel speed and vehicle speed positive, limited integrators are used in this model. The results obtained from the above ABS model which is developed for single wheel are discussed in the results and discussion section.

C.CARSIM Model of ABS Interlinked With Matlab for Four Wheels

To overcome the disadvantages of modeling the ABS through a single wheel the CARSIM model of ABS is developed and interlinked with Matlab. The model developed is for the hatchback and van segment vehicle so as to differentiate the ABS model behavior for two vehicle having different weight considerations. CARSIM provides an option to select the type of vehicle for which we want to develop the ABS model. The model is developed to analyze the ABS system behavior for the double lane change process. The coefficient of friction for the road is taken as 0.6. The vehicle speed is taken as 100 Km/hr. on a straight road. The results obtained are for the parameters such as wheel cylinder pressure, wheel speed behavior, vehicle speed, steering angle behavior, slip ratios. The overall CARSIM model of ABS interlinked with Matlab is shown in the fig 3.

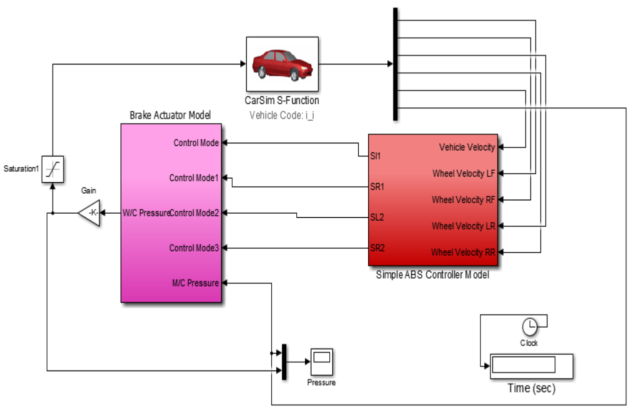

Fig 3: CARSIM model of ABS interlinked with Matlab

The input parameters like vehicle velocity, wheel velocity, and master cylinder pressure are imported from the CARSIM environment and are given to the simple ABS controller model. The master cylinder pressure is set to be 4MPa for hatchback segment and 2 mega Pascal for the Van segment. In the ABS controller model the slip ratios are calculated for each wheel and these value are then supplied to the brake actuator model for calculating the wheel cylinder pressure that is to be supplied to each wheel's wheel cylinder. These values of wheel cylinder pressure are exported to the CARSIM software and ABS model behavior is analyzed by observing the results. The simple ABS controller model is shown in the fig 4.

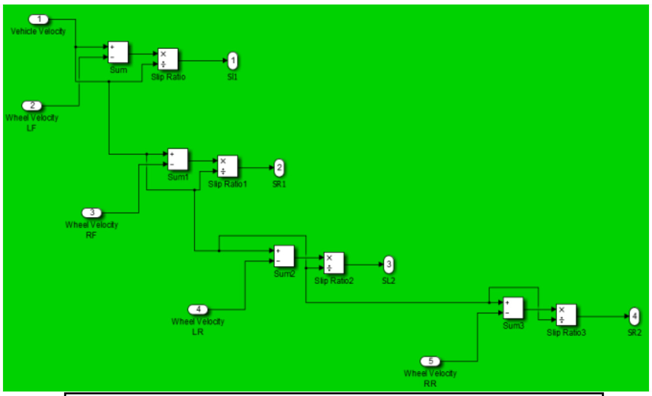

Fig 4: simple ABS controller model for slip ratio calculation

In the ABS controller model the slip ratios of each wheel are calculated. The wheel speed is subtracted from vehicle speed by using sum block. The result of this subtraction is given to the divide block where this value is divided by vehicle speed to obtain the slip ratio. This mathematical calculation is performed for each of the wheel and then these values of slip ratios are given to brake actuator model. The brake actuator model is shown in the fig 5. This model at the end gives the required wheel cylinder pressure that is to be applied to each wheel of vehicle. Master cylinder pressure is taken as an input from the CARSIM environment.

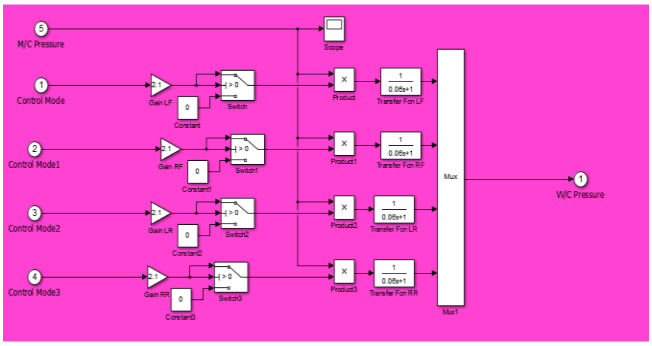

Fig 5: Brake actuator model for wheel cylinder pressure calculation

Slip ratios obtained from simple ABS control model is passed through the gain block having value of 2.1 and then is passed through the switch block. The switch block acts as a comparator and has 3 input ports. If condition of second input port is satisfied then it passes the value through port 1. The master cylinder pressure is multiplied by this value and then is passed through the first order system to obtain the required wheel cylinder pressure. This wheel cylinder pressure is then exported to the CARSIM environment and gets applied to each wheel and then we can analyze vehicle performance in the animator window.

III. Results and Discussion

The results obtained from the Matlab model of ABS for single wheel shows the performance of parameters with and without ABS. The results obtained are as follows:

- Relative slip characteristics with ABS
- Relative slip characteristics without ABS
- Vehicle speed and wheel speed behavior with ABS
- Vehicle speed and wheel speed behavior without ABS
- Stopping distance with ABS

- Stopping distance without ABS

The relative slip characteristics with ABS is shown in fig 6.

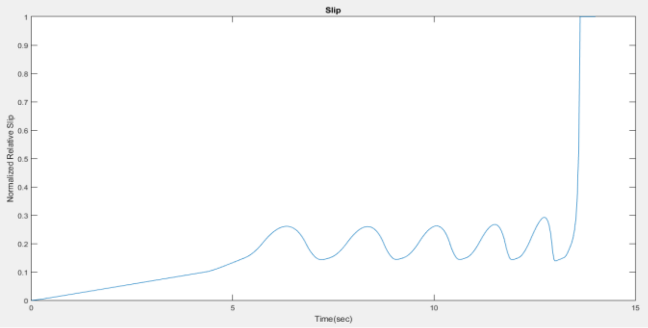

Fig 6: Relative slip characteristics with ABS

As seen from the fig 6 the slip ratio of the wheel after application of ABS comes to value of 1 at the time instant of around 13 sec. This indicates that the slip wheel locking condition is avoided and wheel doesn't come to rest instantly after application of brakes. On the other hand the relative slip characteristics without ABS is shown in the fig 7.

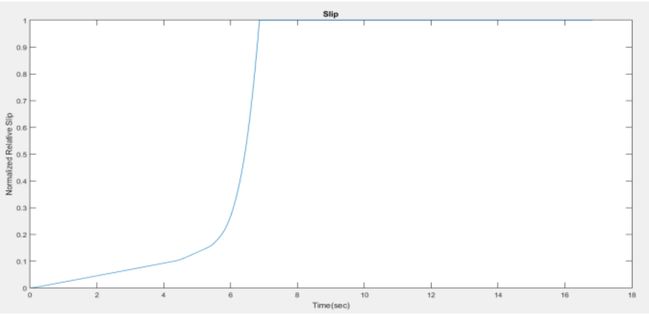

Fig 7: Relative slip characteristics without ABS

As seen from the fig 7 the slip ratio of the vehicle reaches to the value within 7 sec if the brakes are applied without ABS system. Thus the wheel locking conditions occurs.The relative study of vehicle and wheel speed behavior is also important in order to analyze the speed variation between two of them. The vehicle and wheel behavior with ABS system is shown in fig 8 below.

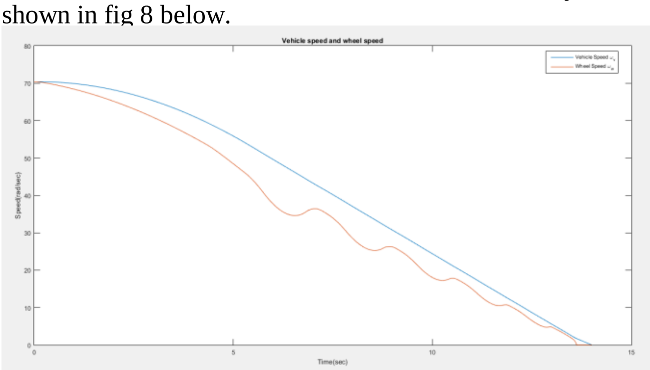

Fig 8: Vehicle speed and wheel speed behavior

As seen from the graph after application ABS when vehicle is running at 70Km/hr. the vehicle speed and wheel speed reduces hand in hand but the wheel speed is always below the vehicle speed so that slip ratio will be always positive and vehicle comes to the rest position after 14 sec. On the other hand the vehicle and wheel behavior without ABS system is shown in fig 9. From fig we can say that without application of ABS the wheel speed suddenly comes to zero at time of 7 sec. Thus skidding of the vehicle occurs without application of ABS at a speed of 70 Km/hr.

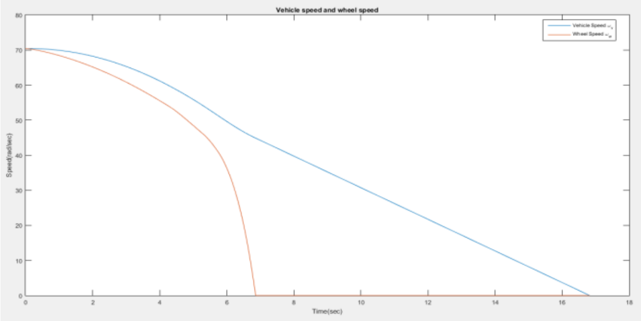

Fig 9: Vehicle speed and wheel speed behavior without ABS

The model developed in the Matlab for ABS also gives the results of stopping distance of vehicle with and without ABS. The stopping distance with ABS is shown in the Fig 10.

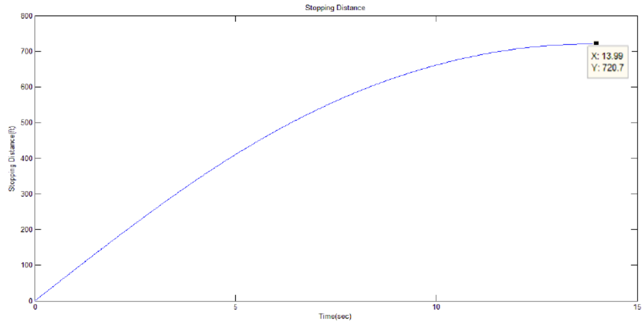

Fig 10: Stopping distance with ABS

As seen from the fig 10 the stopping distance with ABS of a vehicle moving with 70 Km/hr. is 720.7 feet but if we see the stopping distance of vehicle without ABS is 806.1 feet. This is shown in the fig 11.

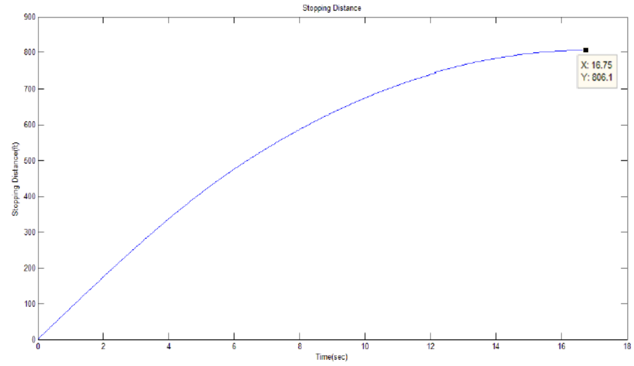

Fig 11: Stopping distance without ABS

Now to obtain the full vehicle simulation of ABS model the CARSIM software which is interlinked with Matlab. From the CARSIM software, number of additional parameter's behavior can be studied as compared to Matlab ABS model. The parameter's result obtained from CARSIM ABS model for hatchback and Van segment vehicle are as follows:

- Wheel cylinder pressure variation
- Steering angle variation during double lane change process
- Slip ratio variation of all four wheels
- Wheel speed behavior of all four wheels
- Vehicle speed behavior of all four wheels

For Hatchback Segment vehicle:

For analyzing the results and behavior of the hatchback segment vehicle the master cylinder pressure is set as a 4 MPa. The wheel cylinder pressure variation for hatchback segment vehicle is shown in the fig 12.

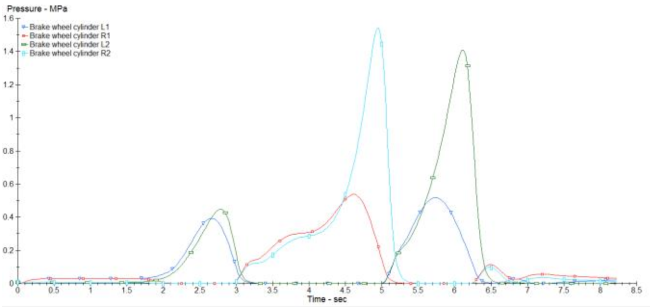

Fig 12: Wheel cylinder pressure variation for Hatchback segment

As seen from the above figure the wheel cylinder pressure variation can be obtained for each wheel. From the graph we can predict that the drastic pressure change occurs for the left rear and right rear wheel in the time domain of 3 sec to 6.5 where major turning process takes place. The above data can be presented in tabular format as shown in the fig 13

	Wheel Cylinder Pressure (MPA)			
Time	Left Front wheel	Right Front Wheel	Left Rear wheel	Right Rear Wheel
0	0.010000	0.010000	0.010000	0.010000
0.5	0.029777	0.029777	0.007492	0.007492
1	0.029266	0.029266	0.006998	0.006998
1.5	0.029304	0.029145	0.007299	0.007155
2	0.055669	0.005245	0.032175	0.000072
2.5	0.332280	0.000001	0.274566	0.000000
3	0.096150	0.015048	0.180834	0.011247
3.5	0.000023	0.221332	0.000046	0.172803
4	0.000000	0.307648	0.000000	0.287027
4.5	0.000000	0.507835	0.000000	0.537781
5	0.000000	0.144878	0.000000	1.445770
5.5	0.412344	0.000039	0.374155	0.000891
6	0.384235	0.000000	1.250704	0.000000
6.5	0.001967	0.114954	0.022815	0.097962
7	0.009231	0.042736	0.000772	0.021758
7.5	0.007344	0.046242	0.000000	0.025558
8	0.017313	0.035606	0.000000	0.015527
8.225	0.022388	0.030507	0.002964	0.010584

Fig 13: Tabular data of wheel cylinder pressure

As the ABS model developed in CARSIM is for double lane change process it is necessary to study the behavior of steering angle during the sharp turning process. The steering angle variation during double lane change process is shown in the fig 14 below.

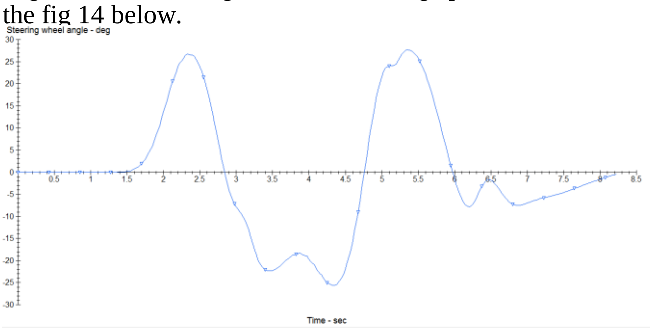

Fig 14: Steering angle variation during double lane change process

As seen from the graph the steering angle of the vehicle varies between +25^{o} to -25^{o}. The steering angle acts as input to the ABS brake system for brake pressure distribution purpose. One of the important parameter in ABS system is slip ratios of four wheels which determines the wheel cylinder pressure that is to be applied. Slip ratio variation for all the four wheels is shown in the fig 15 below

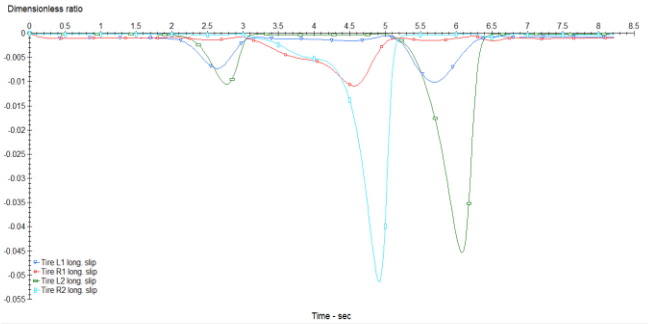

Fig 15: Slip ratio variation for all the four wheels change

As seen from the graph major change in the slip ratio occurs in the left rear and right rear wheel of the vehicle as during turning more change in the wheel velocity occurs at these wheels. The wheel speed behavior of the four wheels is shown in the fig 16 below.

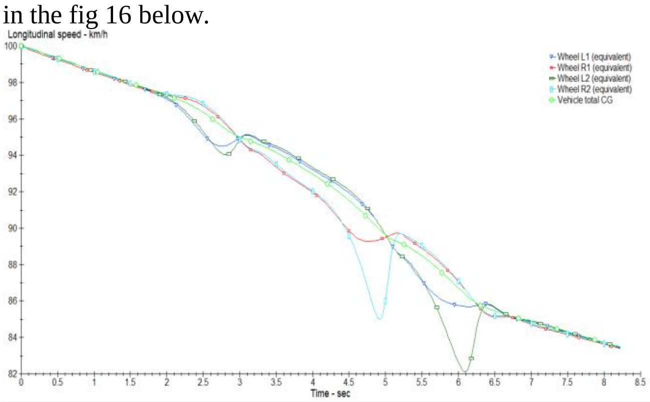

Fig 16: Wheel speed behavior

As seen from the graph major change in the wheel speed occurs in the left rear and right rear wheel of the vehicle due to sharp turning in time domain of 5 sec to 6.5 sec. Now it is necessary to study the vehicle speed behavior so as to compare the vehicle speed and wheel speed characteristics during application of ABS. The vehicle speed behavior is shown in the fig 17.

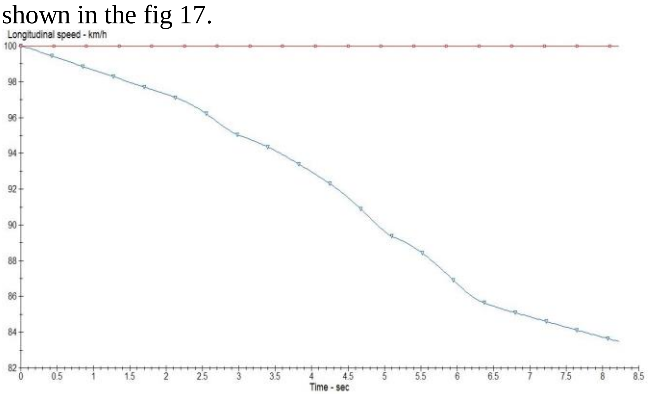

Fig 17: Vehicle speed behavior

For Van Segment vehicle:

Similar results can be obtained for the Van segment vehicle as the hatchback segment vehicle. For analyzing the results and behavior of the hatchback segment vehicle the master cylinder pressure is set as a 2 MPa.

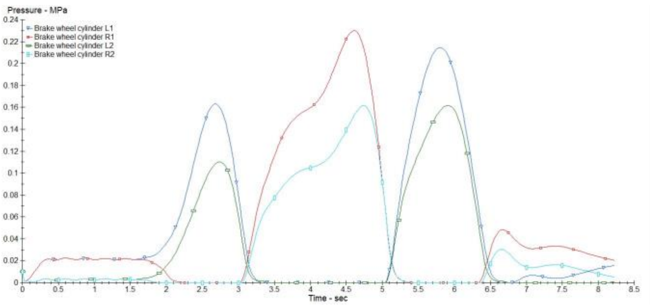

Fig 18. Wheel cylinder pressure variation for Van segment

As seen from the fig the wheel cylinder pressure variation can be obtained for each wheel. From the graph we can predict that the drastic pressure change occurs for almost all the wheels due to the weight of the vehicle in the time domain of 2 sec to 6.5 where major turning process takes place. The steering angle variation during double lane change process is shown in the fig 19. As we can see from the figure that steering angle of the vehicle varies between $+35^{o}$ to -35^{o}. The steering angle acts as input to the ABS brake system for brake pressure distribution purpose.

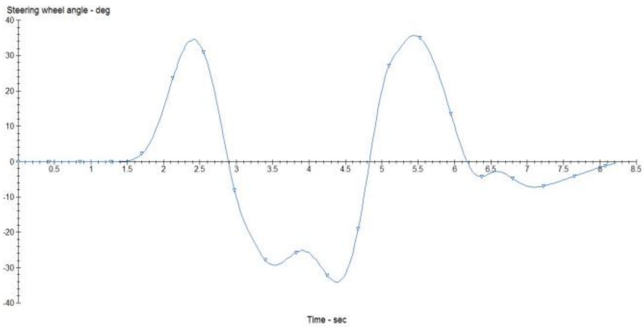

Fig 19: Steering angle variation during double lane change process

Important parameter in ABS system is slip ratios of four wheels which determines the accurate wheel cylinder pressure that is to be applied. Slip ratio variation for all the four wheels is shown in the fig 20 below.

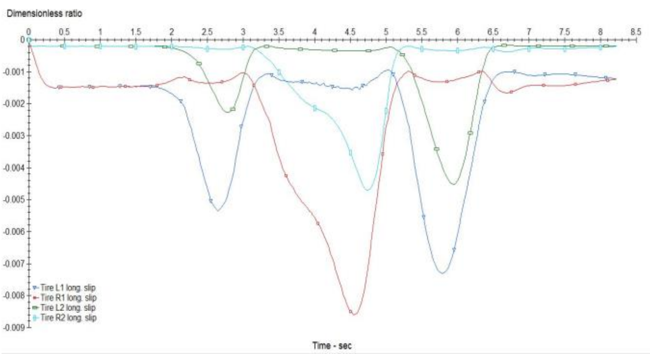

Fig 20: Slip ratio variation for all the four wheels change

As seen from the graph major change in the slip ratio occurs in almost all the wheels of the vehicle. The maximum slip ratio obtained here is 0.09 for the right front wheel. The wheel speed behavior of the four wheels is shown in the fig 21.

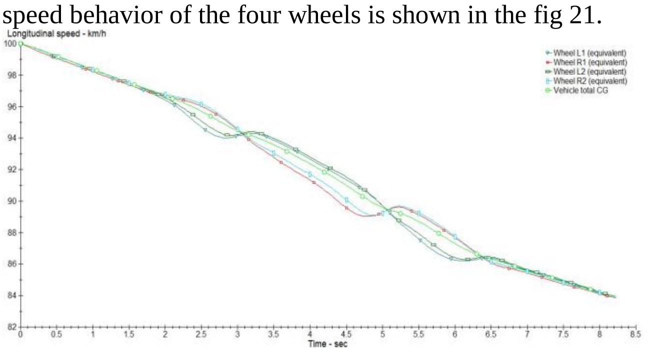

Fig 21: Wheel speed behavior

As seen from the graph all wheel speed changes occurs in the same manner. There is no any drastic change in any of the wheel speed as brake fluid pressure is applied evenly to all the four wheels. It is necessary to study the vehicle speed behavior so as to compare the vehicle speed and wheel speed characteristics during application of ABS. The vehicle speed behavior is shown in the fig 22.

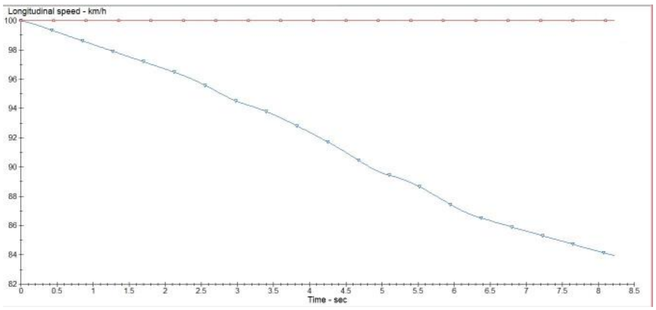

Fig 22: Vehicle speed behavior

As seen from the graph the vehicle speed reduces from the 100Km/hr. to around 83 Km/hr. in time of 8.22sec due to lane change.

It shows that the complete ABS model can be developed for all the four wheels of the vehicle by using CARSIM software. The model is developed for the two most widely used segments of the vehicle such as hatchback segment and van segment. The detailed variation in the ABS parameters such as slip ratio, wheel cylinder pressure is obtained and represented in the tabular format. Also the performance of ABS model developed in the MATLAB is studied and results are obtained for the same. The results obtained from both the models are compared and it is seen that the model which is developed in the CARSIM software gives more accurate and precise results than the model in the Matlab software

IV. CONCLUSIONS

- Single wheel ABS model is developed in the MATLAB and its performance is studied.
- To overcome the disadvantages of ABS model i.e. developed in the MATLAB the complete four wheel ABS model is developed for the hatchback back segment and van segment car in the CARSIM software interlinked with the MATLAB.

- The results obtained in the CARSIM software are more accurate and detailed.
- The model behavior can be studied by taking into account the different coefficient of frictions so as to obtain the different road conditions.

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