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Analysis of Anti-Lock Braking System of an Automobile using MATLAB Simulink

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ABSTRACT

In this paper, the analysis of the anti-lock braking system of a four-wheeler is carried out using MATLAB Simulink providing input conditions of the slip factor and vehicle velocity. The different aspects of calculations and analysis have been done MATLAB/Simulink environment. A conventional on-road 4-wheeler is considered for Analytical Modeling. A linear dynamic system of the model is created and accordingly, the mathematical equations are written. The Simulink model corresponding to the equations is made in MATLAB Simulink. The system is simulated under step input conditions to get the desired performance characteristics output.

Keywords - MATLAB, Simulink, Slip factor.

1. INTRODUCTION

An anti-Lock braking system (ABS) is used in modern vehicles to avoid slipping and locking of vehicle wheels after the brakes are applied. It is a vehicle safety system; the controller is provided to control the generated torque to maintain the optimum slip ratio. The slip ratio is corresponding to the vehicle speed and wheel rotation. The slip rate is maintained at an optimal target slip using continuous control during braking. ABS regulates the brake line pressure independent of the pedal force, to bring the wheel speed back under the slip level range that is necessary for desired optimal braking performance. An ABS consists of a hydraulic modulator, wheel speed sensors, and an electronic control unit (ECU). The anti-lock braking has a feedback control system that regulates and adjusts the brake pressure in response to wheel angular velocity and wheel deceleration to prevent the wheel from locking up. This paper aims to analyze the anti-lock braking system using a bang-bang controller used in the Simulink model. Step input conditions are quick to simulate and can be useful to initialize when as of now not much is known about the system being studied.

2. OBJECTIVES

1. Performance analysis of anti-lock braking system of a conventional four-wheeler using MATLAB Simulink under step input condition.

2. Using MATLAB Simulink interface to perform various calculations and study the results by making a linear dynamic model and feeding governing equations accordingly.

3. To obtain graphical characteristics output from the system simulated corresponding to the input conditions.

4. To make use of the Bang-Bang Controller and implement it in the Simulink model to check its calculative functionality.[1]

3. ABS

An anti-Lock braking system (ABS) is used in modern vehicles to avoid slipping and locking of vehicle wheels after the brakes are applied. It is a vehicle safety system; the controller is provided to control the generated torque to maintain the optimum slip ratio. The slip ratio is corresponding to the vehicle speed and wheel rotation. The slip rate is maintained at an optimal target slip using continuous control during braking. ABS regulates the brake line pressure independent of the pedal force, to bring the wheel speed back under the slip level range that is necessary for desired optimal braking performance. An ABS consists of a hydraulic modulator, wheel speed sensors, and an electronic control unit (ECU). The anti-lock braking has a feedback control system that regulates and adjusts the brake pressure in response to wheel angular velocity and wheel deceleration to prevent the wheel from locking up. This paper aims to analyze the anti-lock braking system using a bang-bang controller used in the Simulink model. Step input conditions are quick to simulate and can be useful to initialize when as of now not much is known about the system being studied.

3. LITRATURE REVIEW

Antilock braking systems square measure closed-loop management devices that forestall wheel lockup throughout braking and as a result, vehicle stability and steering are maintained. System parts include a wheel-speed device, a hydraulic modulator, and an Electronic Management/Control Unit (ECU) for signal process and management and triggering of the signal lamp and the actuators within the hydraulic modulator. ABS functions by detecting the onset of wheel lock-up, because of a high braking force, and so limiting the braking pressure to stop wheel lock-up. The ECU acknowledges the wheel lock-up as a pointy increase in the wheel speed. Braking force is reapplied till the onset of wheel lock-up is once more detected at that purpose it once more reduces the brake force during a closed-loop system method. The cyclic application and reduction of braking force ensure that the brakes operate close to their most effective purpose and maintain steering management. This cyclic application is additionally answerable for the rhythmical that a driver feels through the treadle once the system is activated. Once the motive force applies the brake, brake slip will increase, and at the purpose of most friction between tyre and paved surface the limit between the stable and unstable vary is reached. At this time any increase in brake pressure won't increase the stopping force; as more brake pressure is applied the friction reduces and also the wheel tends towards skidding. On a wet or icy surface, the degradation in friction is giant because the wheels lock up, whereas on a surface like dry hydrocarbon the degradation in braking force is comparatively little. The sensible result's that vehicle stopping distances with fastened wheels square measure almost like those wherever ABS is working on dry hydrocarbon and far larger on wet surfaces. The advantage of ABS that's most publicized is that it provides the motive force the power to steer throughout emergency braking. During a vehicle with a standard braking system because the wheels tend towards lock-up, the lateral friction that allows steering reduces greatly and approaches zero once absolutely fastened. By preventing wheel lock-up lateral friction between the paved surface and also the tyre is maintained at a high level, as a result of that vehicle steering management in ABS-fitted vehicles is maintained throughout emergency braking.[2].

4. ANALYSIS AND FORCE DISTRIBUTION

4.1 Static Load Distribution

The static load of the vehicle at rest, i.e., the weight(W) acting at the center of gravity is balanced by the reaction forces acting on the front and rear wheels (W1 and W2 respectively).

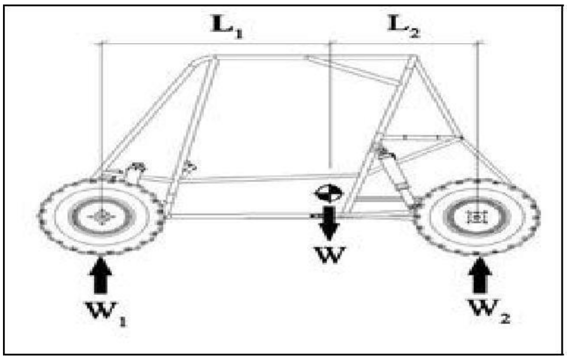


Figure 1. Static Load Distribution Schematic

4.2 Dynamic Load Distribution

The dynamic loads of the vehicle in motion, i.e., the weight(W) and force due to acceleration(ma) are balanced by the reaction forces acting on the rear and front wheel in vertical (L_{ra} and L_{fa}) and horizontal (R_{bf} and F_{bf}) direction.

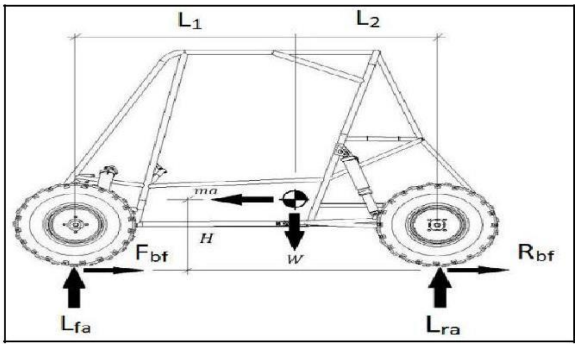


Figure 2. Dynamic load distribution schematic

4.3 Force calculation on the wheels

The net forces acting on the wheel are displayed as follows.
μ_T : Coefficient of friction
W_f : Wheel weight
ω : Wheel's angular velocity [3][4].

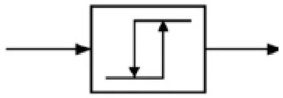
1) Tyre Torque= μNR
   μ- Co-efficient of friction
   N- Normal Force per wheel= mg/4
   R- Wheel Radius

2) Equivalent vehicle angular acceleration= -(Tyre Torque/ Vehicle mass* Wheel radius)

3) Equivalent vehicle angular velocity= Integral of angular acceleration.

4) Relative Slip= 1-(vehicle angular velocity/ wheel angular velocity) [4]

5) Bang-Bang Controller
Output =1 if, input > 0
Output =-1 if, the input< 0. [5]



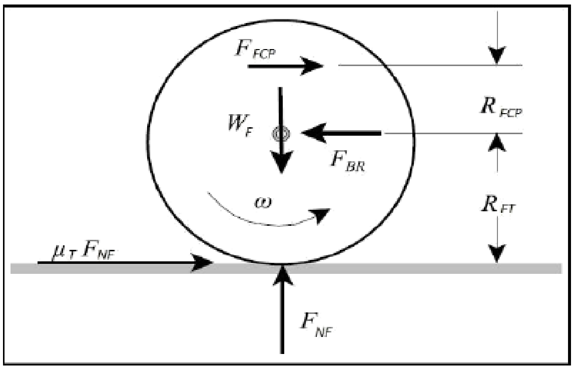


Figure 3. Force Distribution Schematic

5. INPUT DATA

NAME	SYMBOL	VALUES	UNIT
Gravitational force	g	9.81	m/s^2
Moment of Inertia	I	5	$Kg.m^2$
Vehicle Mass	m	75	Kg
Wheel Radius	R	1.25	m
Vehicle Velocity	V_0	44	m/s

6. SIMULINK MODEL

The entire model is divided into 3 branches.
1. The first branch calculates the error between the actual wheel slip and the desired wheel slip.
2. The second branch calculates the tyre torque and eventually gives the vehicle angular velocity.
3. The third branch calculates the relative slip by taking wheel speed and vehicle angular velocity as inputs.F

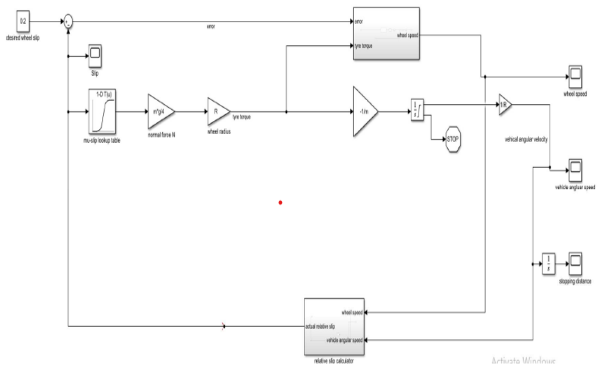
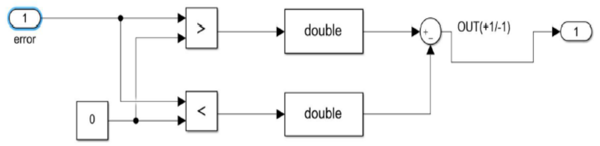


Figure 4. Final Simulink model

The end model will be looking like this as shown in Fig.7.1. 0.2 is the desired slip and we will be calculating the actual speed by the vehicle speed and the wheel speed from the scope outputs. The difference between these 2 slips will be used to drive a controller that controls the braking torque.
We start off creating the model by setting up the desired slip which is 0.2. Now according to the formula given below, we will input the relative slip by calculating through the given formula. Vehicle angular velocity is equivalent to vehicle angular velocity. A summing joint is used and one of its terminals is made negative and connected to the desired wheel slip. The other end terminal will be used to calculate the actual relative slip. The output will be the error between the actual and desired wheel slip. For the actual wheel slip, we will be calculating both wheel angular velocity and the vehicle angular velocity and from there we will calculate the relative slip. Now to calculate the wheel angular velocity and vehicle speed, we will need the coefficient of friction between the tires and the ground. The coefficient of friction will be changing as the wheel slip changes. For the variation of wheel slip and the coefficient of friction, we will be adding a lookup table and the input will be attached to the actual wheel slip. This will output the coefficient of friction. From here we added all the values and we can get the coefficient of friction from the lookup table block and we have to multiply it with the normal force and radius of the wheel. The normal force is calculated by the formula as shown below. Now we will add another gain block for the normal force. Next, we will input the wheel radius using another gain block. The output here from the two gains will be the tyre torque. From the tyre torque, we will be finding the wheel speed. To do this we will need a bang-bang controller. To implement this controller we will use a constant block with zero as its value and we will use 2 comparison operators, one with less than and the other with greater than. The error branch of the summing joint will be connected to the inputs of these comparison operators. Now a data type conversion for

the comparison controllers will be done from integer to double. The output of these operators will be connected to a summing joint to give the output as +1 or -1 according to the input. Now the circuit from the 0 constant block to the output summing point can be integrated into one block and will be SUB-SYSTEM 1.

This subsystem uses Bang Bang controller for error calculation.



This subsystem will be renamed the bang-bang controller. Next, a transfer function will be added which represents the hydraulic lag once the brake is applied. This function is completely arbitrary as of now. The output of this transfer function can be integrated by an integrator block over time to get the braking torque. The upper saturation limit of the integrator will be set to 1000. The difference between the braking torque and the tyre torque can be computed to compute the deceleration of the vehicle. Now we will add a summing block in which the negative terminal will be joined to the braking torque and the positive terminal will be joined to the tyre torque. The output from this summing block will be divided by the moment of inertia to compute the acceleration. (Torque divided by the moment of inertia is the acceleration (deceleration in this case). Now by integrating the deceleration we get the velocity of the wheel. The initial velocity of the vehicle is calculated by the formula V0/r as shown earlier. This will give the wheel speed. Here we will create a block right from the bang-bang controller to the wheel speed in the form of another subsystem i.e. SUB-SYSTEM 2. This block will take the error signal and tyre torque and input and will output the wheel speed. The graphical behavior can be obtained by connecting a scope to the wheel speed.

This subsystem evaluates the braking torque and subtracts it with tyre torque to calculate the wheel speed.

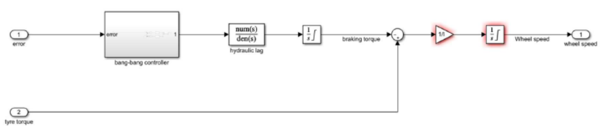


Figure 5. SUB-SYSTEM 2

Next what needs to be computed is the vehicle speed. This can be calculated by the parameters that are tyre torque, Vehicle mass, and wheel radius as shown in the formula section. The mathematical function will be implemented to get the vehicle's angular velocity. A gain block will be added with the value of -1/m. the (-) sign here denotes that the vehicle is decelerating. Here 'm' is the total mass of the vehicle. The value from this gain block will be input into an integrator block to obtain the vehicle's linear velocity. The upper saturation limit is set to 1000. Wheel's initial velocity is set to V_0/r. Now to obtain the vehicle's angular velocity the value needs to be divided by the wheel radius. A scope is added at the end to obtain the graphical behavior. In case the vehicle speed reaches zero, the simulation needs to be stopped. For this action, a stop operator is used to terminate the simulation as the value reaches zero. Now we can calculate the relative slip from the wheel speed and the vehicle's angular velocity. The stopping distance can be calculated from the vehicle's speed by integrating the value. A scope will be added to obtain the simulation result. After doing this the vehicle's actual slip can be obtained from the vehicle speed and the wheel speed. To do that, a divide operator is used to divide the wheel speed and the vehicle speed. The product terminal will be connected to the wheel speed and the division terminal will be added to the vehicle's angular speed. To compute the relative slip the value needs to be subtracted by one (done by creating a constant block with the value 1). A summing block with a negative sign is inserted. The positive terminal is connected with the constant and the negative terminal is connected with the multiplication block. The 3 operators namely the multiplication block, constant block, and the summing block with are complied as SUB-SYSTEM 3(relative slip calculator). A scope will be set up to monitor the actual wheel slip over time.

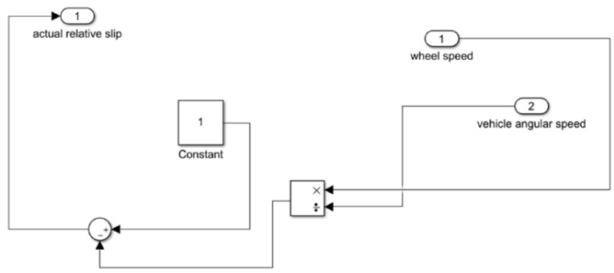


Figure 6. SUB-SYSTEM 3

Now after creating the Simulink model with all the required governing equations, the input variable parameters need to be initialized with some values. Thus in MATLAB, the values to the variables are assigned. The assigned values are shown in the table. Now after setting up the simulation time, the Simulink model is run. After the run is complete, the graphical results can be obtained from the scopes that have been added.

7. SLIP-COEFFICIENT VARIATION

A graph indicating the general behavior of the wheel on application of brakes is obtained by considering an arbitrary set of values for Coefficient of Friction and Slip, From the graph we make assessment that the Coefficient of Friction is maximum for the slip value=0.2 and hence the desired slip value is taken as 0.2 for simulation in the Simulink Model. [6]

µ	Slip
0	0
0.05	0.4
0.1	0.8
0.15	0.97
0.2	1
0.25	0.98
0.3	0.96
0.35	0.94
0.4	0.92
0.45	0.9
0.5	0.88
0.55	0.885
0.6	0.83
0.65	0.81
0.7	0.79
0.75	0.77
0.8	0.75
0.85	0.73
0.9	0.72
0.95	0.71
1	0.7

Figure 7. Coefficient of Friction vs slip ratio Table

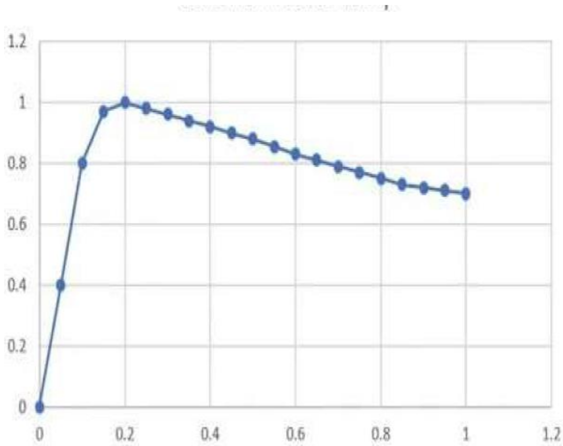


Figure 8. Slip ratio Vs Co-efficient of friction graph

8. GRAPHICAL BEHAVIOUR

1)Slip:
When the ABS is Functioning (ON), the desired sip is set to 0.2. As and when the brakes are applied drastically, the wheel locks up and slip rate starts increasing. As the slip value surpasses 0.2, the ABS controller regulates and adjusts the brake pressure and releases the brakes. As the wheel and vehicle speed are not in sync, the brakes are re-applied. This cycle continues till the slip value is under the reference value range. This leads to the synchronization of vehicle and wheel velocity.

2)Wheel Speed

The wheel speed decreases and increases intermittently due to the repetitive apply-release mechanism of brakes during the sudden braking to match the wheel and vehicle velocity. Hence the graph displays the cyclic behavior of decreasing wheel speed

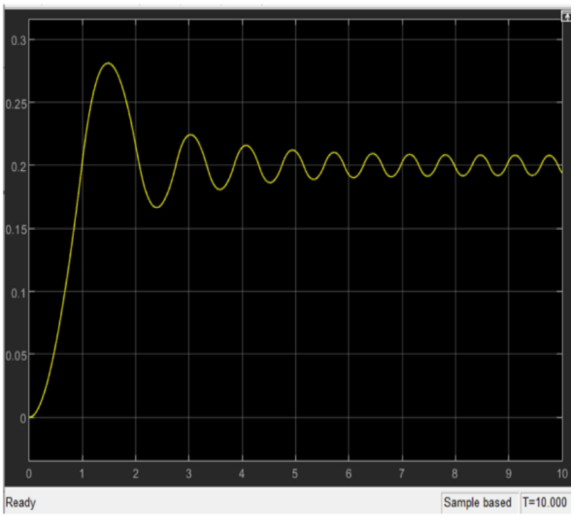


Figure 10. Slip variation with respect to time

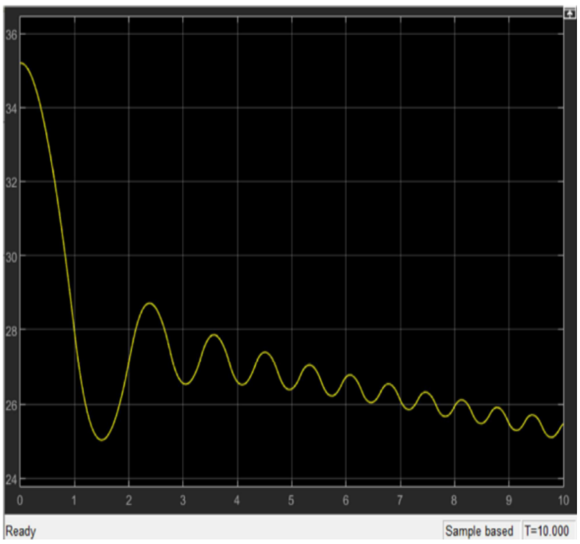


Figure 10 Wheel speed variation with time

3)Vehicle Angular Speed
The graphical behavior below shows vehicle angular speed decreasing linearly with respect to time as a result of the deceleration caused by braking force.

4)Stopping Distance
Stopping distance is a function of the braking force, vehicle initial velocity and vehicle mass. As the vehicle mass and initial velocity is kept constant, the stopping distance declines linearly with respect to time as the braking force is increased.

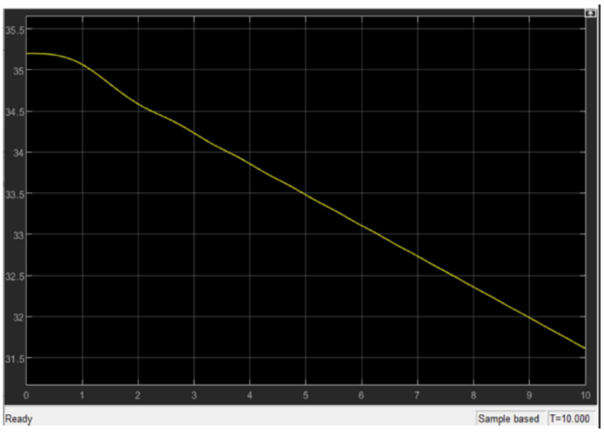


Figure 11. Vehicle Angular speed with time.

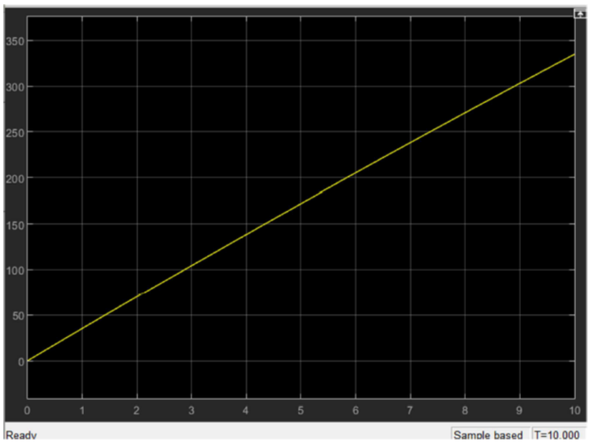


Figure 12. Stopping distance variation

9. CONCLUSION

In the above work, the simulation and analysis of the ABS in a conventional four-wheeler vehicle is done using MATLAB Simulink. On completion of this work, the conclusion that we drawn from simulation is that while braking with Bang-Bang Controller mode the wheel speed and the vehicle speed sets down at the same time. The slip, stopping distance, wheel speed and relative slip of the vehicle is found along with the graphical behaviors.[6] We also explored that the Anti-Lock Braking Systems are much more effective and relatively safer than conventional disc brakes and hydraulics brakes, as they reduce the Stopping Distance while simultaneously provide the Steering control to the driver in a panic braking situation.

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