MATLAB and Simulink of Vehicle Traction Control

A Project Report

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SCHOOL OF MECHANICAL & MANUFACTURING ENGINEERING

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NUST

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CHAPTER 1. INTRODUCTION

1.1 The Aim of the Project

Today, technology is evolving and by the usage of smart systems we can improve the existing to work up to their maximum efficiency. Automobiles today are equipped with various technologies such as ABS, traction control and cruise control etc. which helps in accommodating the driver’s safety and to increase the fuel economy of the car. More ever, traction control can help you on roads when the car is on two different surfaces because due to difference in traction on one side of wheels, your car can skid and the driver can lose control.

To resolve this problem, we can implement the concepts of control and sensors where we can gather live data from the road such wheel slip and wheel rpm and by using this data, we can control the car’s maneuvers. One possible technique of achieving this is by controlling the braking system to control the slip of the particular wheel that is slipping.

By using such control systems, the driver’s safety is improved ten-fold and the actual probability of involving in an accident is lowered.

1.2 Literature Review

1.2.1 Wheel Base:

Wheel base is the center-to-center distance of the wheel when viewed from the side.

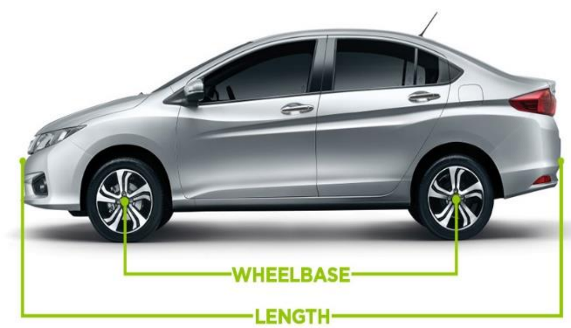


Figure 1 Wheel base of the car

1.2.2 Wheel Track:

Wheel tack is the center-to-center distance of the wheel when viewed from the front.

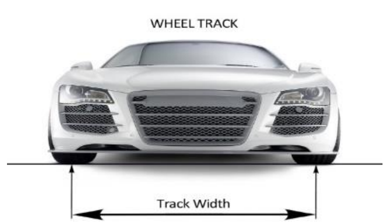


Figure 2 Wheel Track of the car

1.2.3 Weight Distribution:

The location of center of gravity if very important parameter when designing disc brakes and basically weight distribution is how much the weight is distributed among the front and rear tyres.

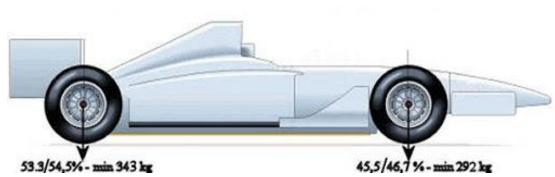


Figure 3 Weight Distribution

1.2.4 Weight Transfer:

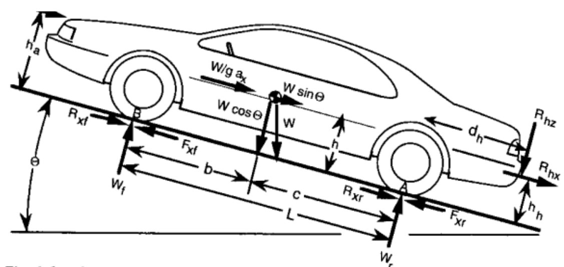


Figure 4 Weight Transfer

During acceleration of the car, the weight transfer occurs from the front tires to the rear tires and opposite happens during braking.

These are governed by these relations:

Equation 1 Static Weight

$$W_{fs} = W\frac{c}{L}$$

$$W_{rs} = W\frac{b}{L}$$

Where,

W_{fs} = Static Front Weight

W_{rs} Static Rear Weight

c = Distance from rear tire to C.O.G

b = Distance from front tire to C.O.G

L = Wheel Base of the Car

W = Overall Weight of Car

For dynamic weight transfer:

Equation 2 Dynamic Weight Transfer

$$W_f = W_{fs} - W\frac{a_x}{g}\frac{h}{L}$$

$$W_r = W_{rs} + \frac{a_x}{g}\frac{h}{L}$$

Where,

h =Height of the C.O.G from the ground

a_x =Linear acceleration of the car

1.2.5 Slip Angle

The longitudinal slip is generally given as a percentage of the difference between the surface speed of the wheel compared to the speed between axle and road surface, as:

1.2.6 Determination of Braking Torque:

We first need to calculate the required braking performance for our chosen vehicle. Remember that brakes that are too powerful may lock the front wheels and brakes too weak may not be able to give the required deceleration to stop the car.

We will utilize equation 1 and 2 but with the fact that the we are decelerating instead of accelerating so we replace a_x with $-D_x$

We get,

Equation 3 Dynamic Load Transfer (Deceleration)

$$W_f = W_{fs} + W\frac{D_x}{g}\frac{h}{L}$$

$$W_r = W_{rs} - \frac{D_x}{g}\frac{h}{L}$$

Where,

$D_x\ is\ there\ deceleration\ of\ the\ body$

The maximum is braking force is limited by the road conditions and peak coefficient of

friction:

Equation 4 Maximum Braking Force

$$B_{f,max} = \mu_p\left(W_{fs} + W\frac{D_x}{g}\frac{h}{L}\right)$$

$$B_{r,max} = \mu_p\left(W_{rs} - W\frac{D_x}{g}\frac{h}{L}\right)$$

Where,

μ_p = Peak coefficient of friction

$B_{f,max} = Maximum\ Front\ Braking\ Force$

$B_{r,max} = Maximum\ Rear\ Braking\ Force$

The total braking force is a function of deceleration i.e.

Equation 5 Relationship between braking force and deceleration

$$D_x = \frac{B_{f,max} + B_r}{M}$$

$$D_x = \frac{B_{r,max} + B_f}{M}$$

Putting in equation 4 we get,

Equation 6 Braking Forces in terms of Peak Friction Coefficient

$$B_{f,max} = \frac{\mu_p (W_{fs} + \frac{h}{L} B_r)}{1 - \mu_p \frac{h}{L}}$$

$$B_{r,max} = \frac{\mu_p (W_{rs} - \frac{h}{L} B_f)}{1 + \mu_p \frac{h}{L}}$$

Now, we can design our disc brakes prior to the above discussion.

Some parameters that are used in design of disc brakes are

1.2.7 Hydraulic Design Parameters For Disc Brakes

1. No of braking pads
2. Force Applied by Driver
3. Leverage Ratio
4. Force Transmitted to Brake Cylinder
5. Diameter of Master Cylinder
6. Effective Radius
7. Pressure Transmitted to Caliper
8. Disc-Pad Coefficient of Friction
9. Braking Force
10. Braking Torque
11. Brake Caliper Piston Diameter
12. Clamp Load Generated
13. Radius of the Wheel

Following relations can be used to find all the design parameters listed above. For our ease we also have constructed a mathematical model in Simulink.

$$\tau_B = B * r_w$$

$$R_e = \frac{D + d}{4}$$

$$F_c = \frac{T_b}{R_e \mu_l n}$$

$$P_{sys} = \frac{F_{driver}}{A_{cylinder}}$$

$$F_{c,gen} = P * A_{calliper} * \mu_l$$

Where,

τ_B = Braking Torque
B = Braking Force
r_w = Radius of the wheel
R_e = Effective Radius
D = Disc useable outside diameter
d = Disc useable inside diameter
F_c = Clamping Load:
T_b = Braking Torque
μ_l = Friction of coefficient between Disc- Required pad and Rotor
n = No of friction faces
P_{sys} = System or brake cylinder pressure
F_{driver} = Force applied by driver
$A_{cylinder}$ = Area of Brake Cylinder
$A_{calliper}$= Area of brake caliper piston
$F_{c,gen}$ = Generated Force

1.2.8 Thermodynamic Design Parameters for Disc Brakes

1. Ambient Temperature
2. Density of Steel (Disc)
3. Effective Volume
4. Convective Coefficient
5. Effective Surface Area
6. Specific Heat of Disc
7. Thickness of Disc
8. Thermal Conductivity of Steel (Disc)
9. Heat Dissipated by convection
10. Change in Temperature
11. Maximum Temperature
12. Braking Time
13. Kinetic Energy of the car

Following relations can be used to find all the thermodynamic parameters listed above.

$K.E = \frac{1}{2}MV^2$

$t = V/D_x$

$P = \frac{K.E}{t}$

$A_{eff} = \frac{\pi}{4}(D^2 - d^2)$

$q = \frac{P}{A_{eff}}$

$T_{max} = \frac{q*t}{A_{eff}*k} + T_\infty$

$q_{out} = h(T_{max} - T_\infty)$

$\Delta T = T_{max} - T_\infty$

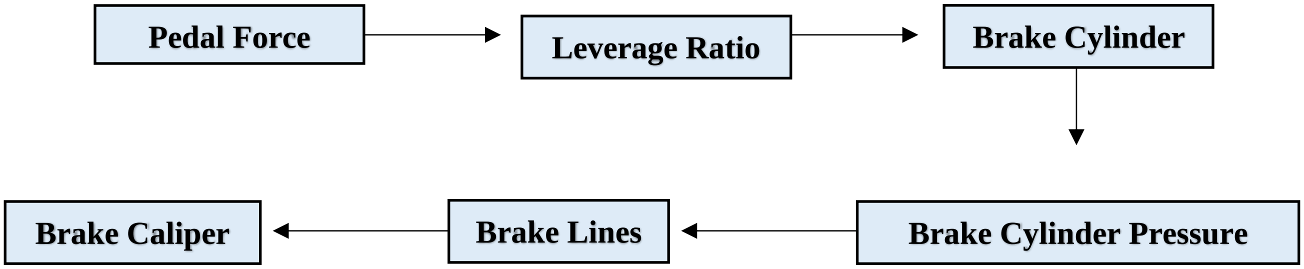
Where,

$K.E =$ Kinetic Energy of the Car
$M =$ Mass of the Vehicle
$V =$ Velocity of the Vehicle
$P =$ Power Transferred
$t =$ Braking Time
$A_{eff} =$ Effective Area of Disc
$q =$ Heat Flux Generated
$q_{out} =$ Heat Flux from Convection
T_{max} = Maximum Temperature Reached
k = Thermal Conductivity
T_∞ = Ambient Temperature

1.2.9 Force and Pressure Flow:

A flow chart has been used to explain what happens to the force applied by the driver.

- The driver applied a force let's say x
- The force is multiplied by the leverage ratio i.e. kx
- The applied force is transferred to brake cylinder piston.
- The pressure generated is $\frac{kx}{A_{cylinder}}$
- Assuming no pressure loss in the brake lines, the brake cylinder pressure is transmitted to the brake caliper piston.
- The force is used to retard the motion by friction.



1.2.10 Engine Displacement:

Engine displacement is the swept volume of the piston inside the cylinder.

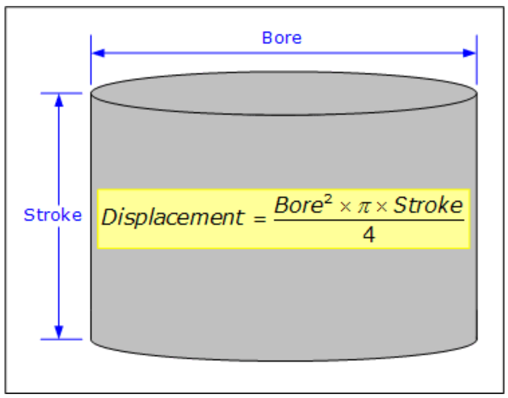


Figure 5 Displacement, Bore and Stroke of the engine

1.2.11 Bore and Stroke:

Bore is the diameter of the cylinder, while the stroke is the distance within the cylinder the piston travels.

1.2.12 Compression Ratio:

The compression ratio is defined as the ratio of the volume of the cylinder and its head space when the piston is at the bottom of its stroke to the volume of the head space when the piston is at the top of its travel.

1.2.13 Ignition Timing

Ignition Timing is a process to deliver spark at correct time. It sets the pointer with respect to the position of the piston as well as the crankshaft's velocity.

1.2.14 Gross Horsepower:

It's the power of the engine when it is not connected. Gross Horsepower of our engine is **10 hp**.

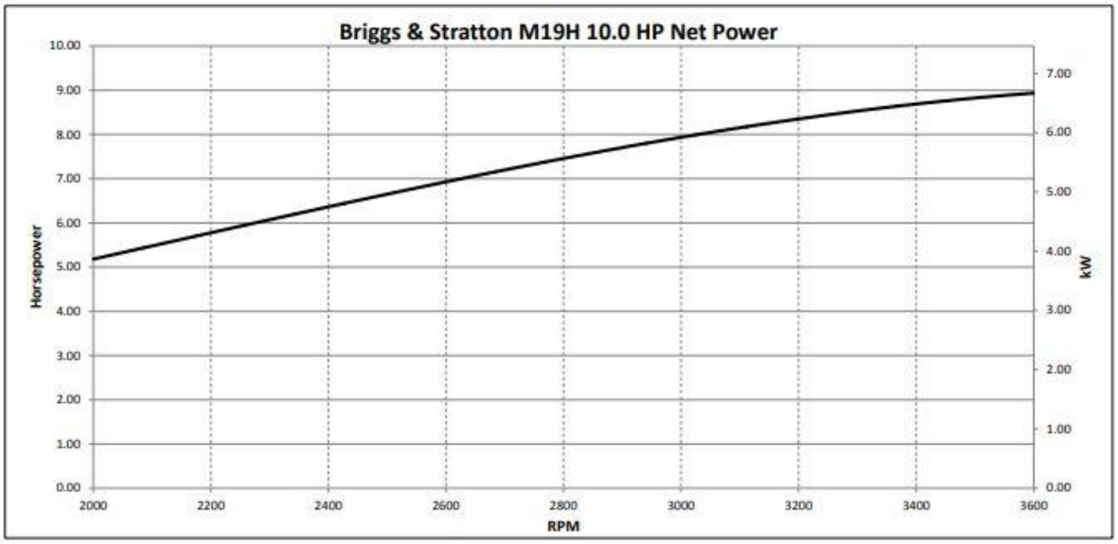


Figure 6 Power-RPM Curve

1.2.15 Calculation of tractive force from engine:

We can calculate tractive force of at the drive wheels from engine by using this formula

$$F_x = \frac{T_e N_{tf} \eta_{tf}}{r} - \{(I_e + I_t)N_{tf}^2 + I_d N_f^2 + I_w\}\frac{a_x}{r^2}$$

Where,

F_x = Tractive force of at the drive wheels
T_e = Engine torque at a given speed (from dynamometer data)
N_{tf} = Combined numerical ratio of the transmission and final drive
η_{tf} = Combined efficiency of the transmission and final drive
r = Radius of the wheels
I_e = Engine rotational inertia
I_t = Rotational inertia from transmission
I_d = Rotational inertia of the driveshaft
I_w = Rotational inertia of the wheels and axle shafts
a_x = Acceleration in forward direction

CHAPTER 2. Modeling the Vehicle in MATLAB:

A vehicle contains different subsystems that are to be combined to develop a complete working model. Different subsystems, such as engine, tires, transmission, brakes and sensors are modeled separately and are then combined later in the model. The complete model is as shown.

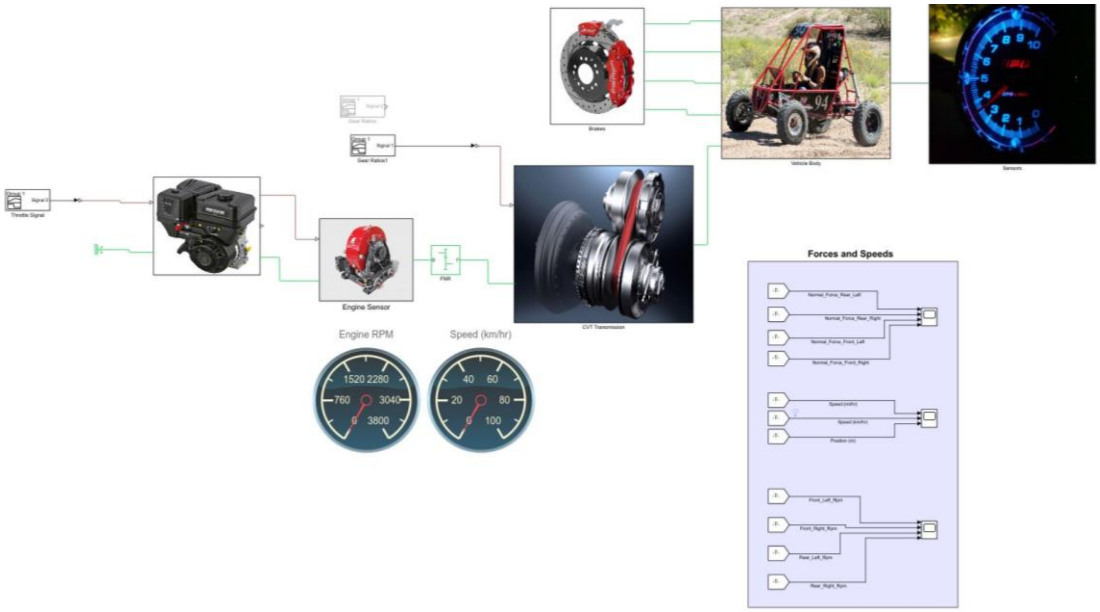


Figure 7 Complete Model

2.1 Model of Brakes

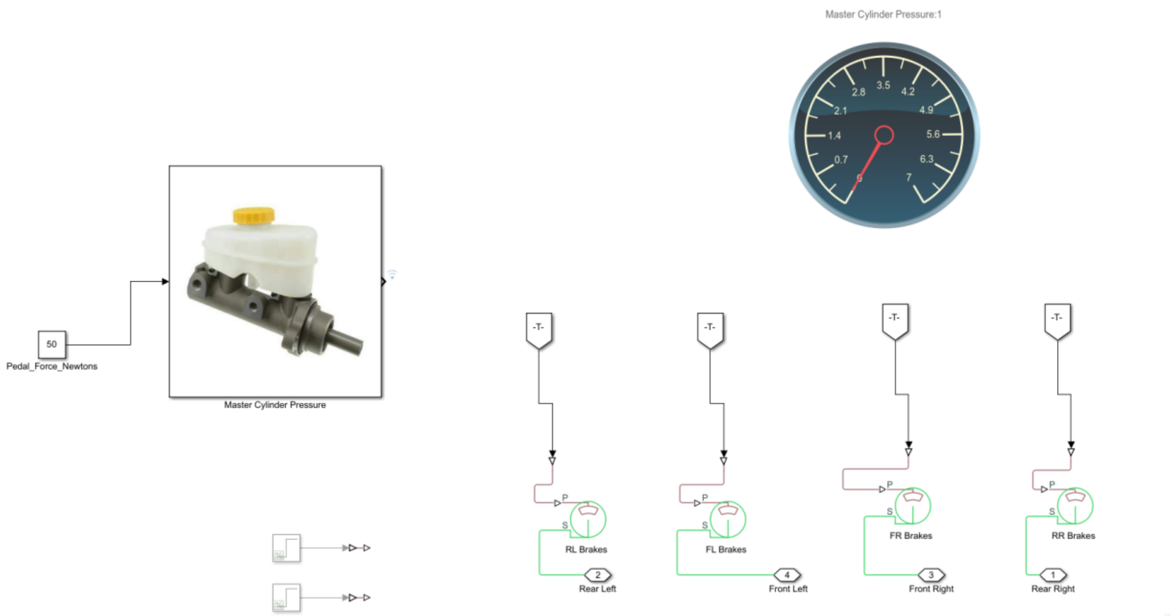


Figure 8 Disk Brakes in Simscape

This braking subsystem working closely with the traction control and basically controls the slip ratio whenever the slip ratio is below or above the required one. For maximum performance the required relative slip ratio is about 0.2.

2.2 Model of Traction Controllers

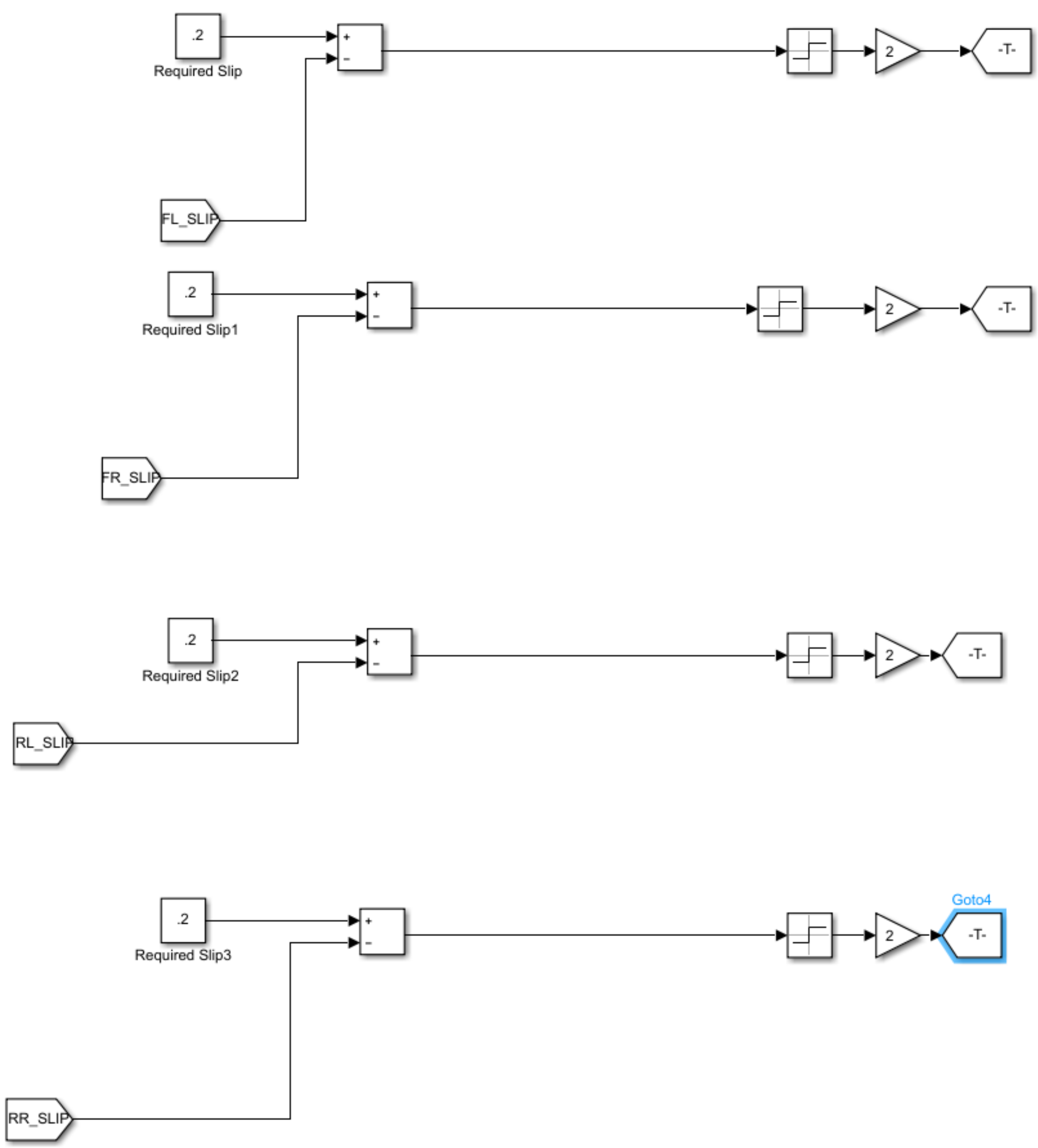


Figure 9 Traction Control

The Traction controller takes relative slip from the tires and calculates the error between the required slip and live slip. If the error is greater or lower than zero then the brake pressure is generated accordingly to control the slip.

2.3 Model of Vehicle

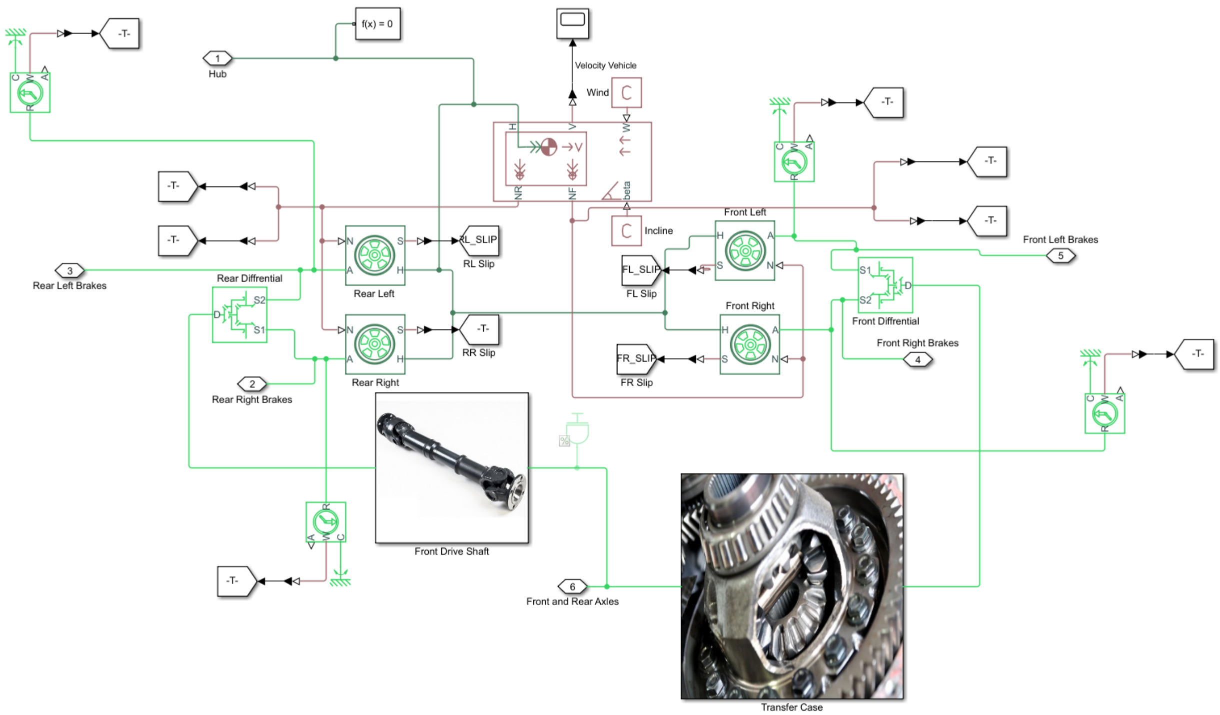


Figure 10 Vehicle Body

The vehicle is modeled as an All-wheel drive system. Basically, the power from the engine is the input which is transferred to transfer case and front drive shaft. The transfer case equally divides the power to all wheels. Different sensors are employed in the model to track and normal force, speed of the vehicle, rpm of the wheels and relative slip.

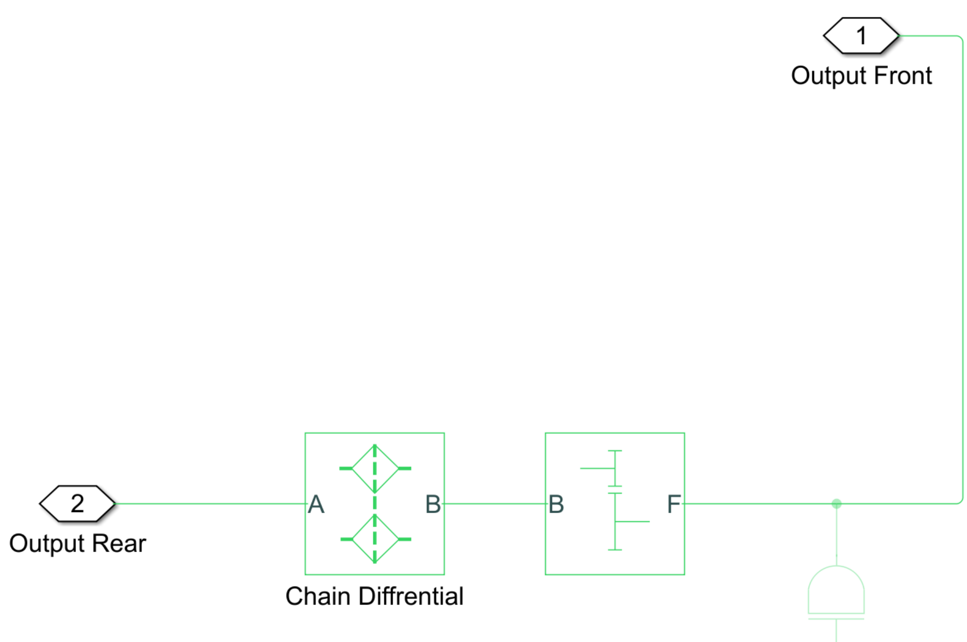


Figure 11 Inside Transfer Case

The transfer case is modeled as a chain differential with a simple gear box so that both wheels can get the same rpm.

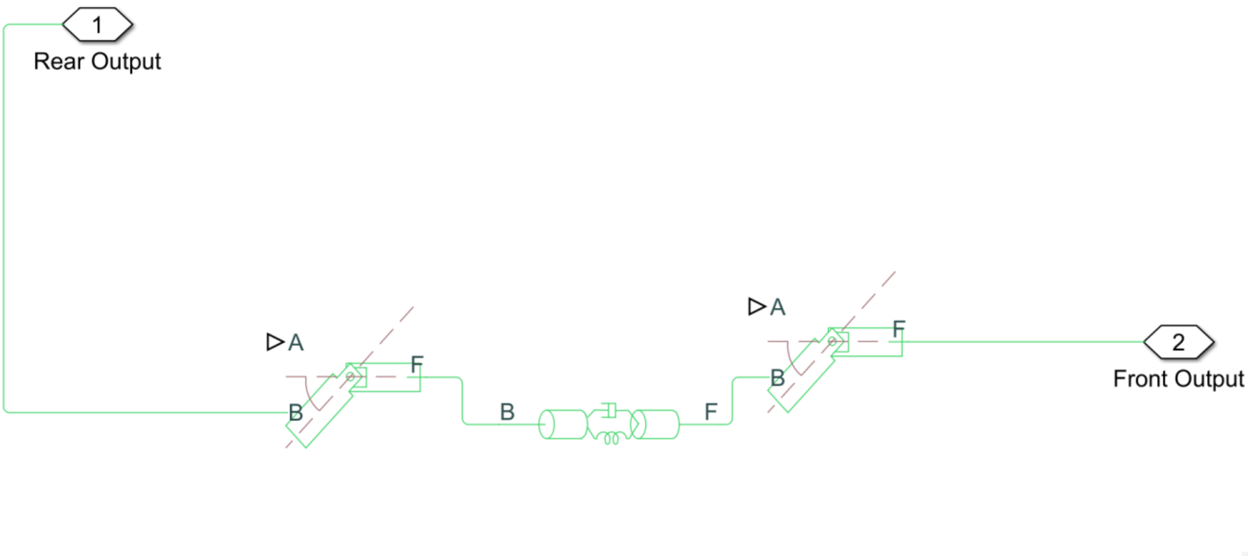


Figure 12 Inside Driveshaft

The driveshaft has two u-joints with maximum angle of 45 degrees.

2.4 Model of Transmission

The transmission is modeled as a CVT which provides unlimited gear ratios from up to 3:1 and 0.43:1. This transmission is further coupled with a gear box namely FNR of a fixed ratio of 6:1 to provide different combined of ratios for different torque requirements.

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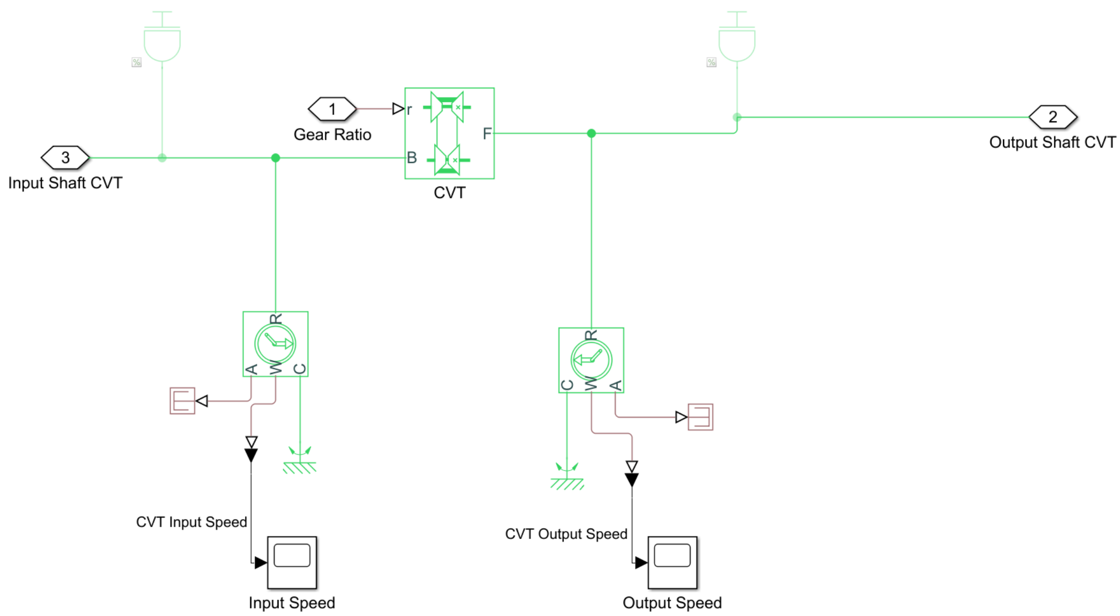


Figure 13 Inside CVT Transmission

2.5 Model of Engine

Briggs and Stratton 10 HP OHV engine was chosen for this model.

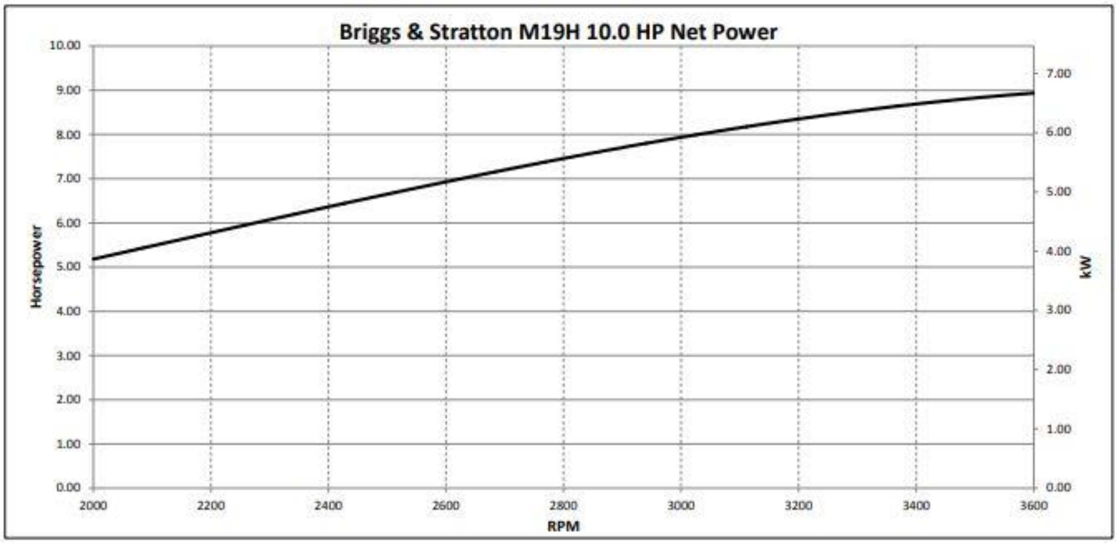
e

Figure 14 Briggs and Stratton Engine Power Curves

A constant throttle single has been provided as the input we get constant power as output. The engine operation should be below the stalling rpm in the model during simulation.

CHAPTER 3. Results:

We can model the car's behavior using different sensors implemented in to the model: The following three graphs shows the common behavior during gear change and acceleration.

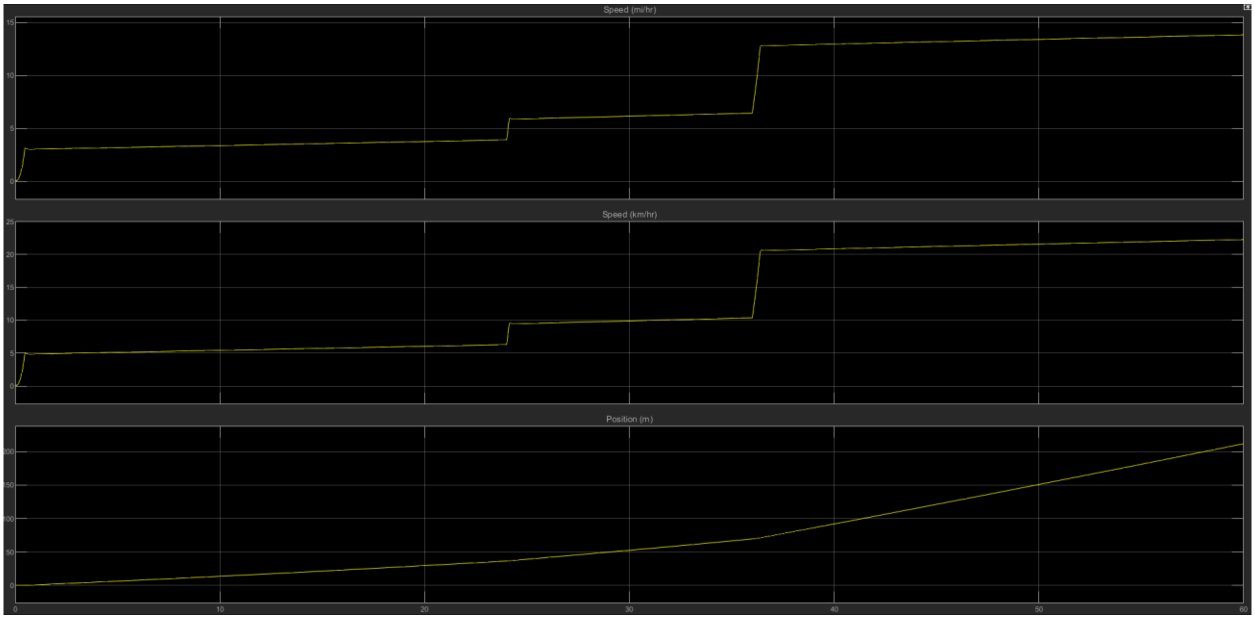


Figure 15 Vehicles Speed

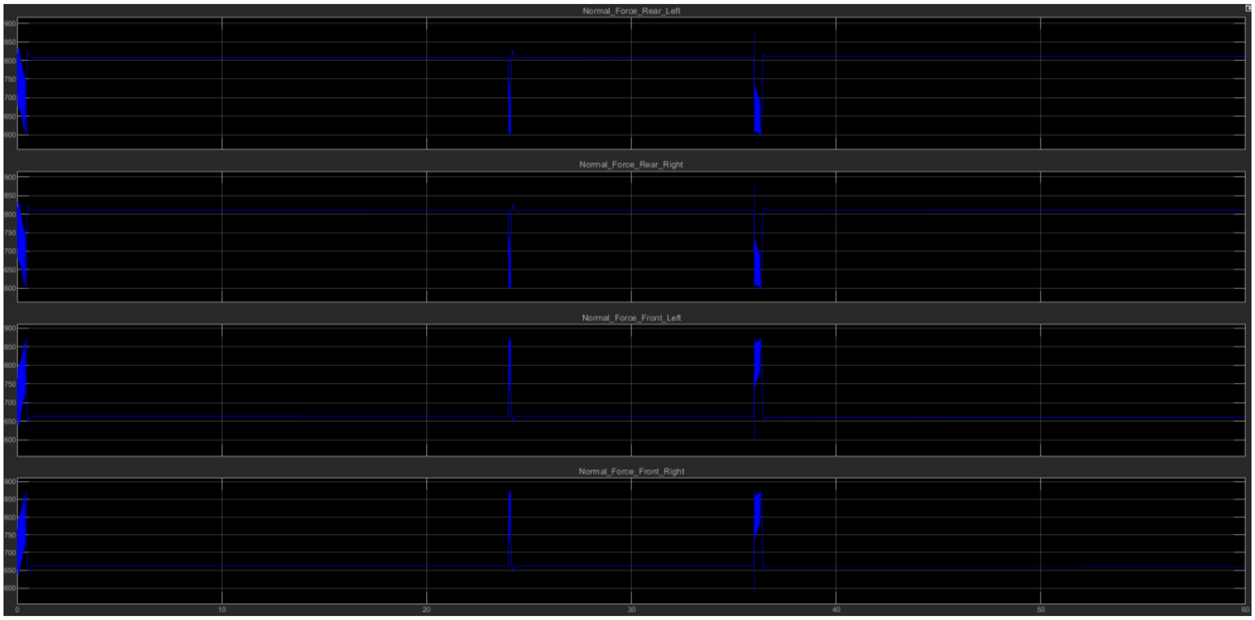


Figure 16 Wheel Normal Force

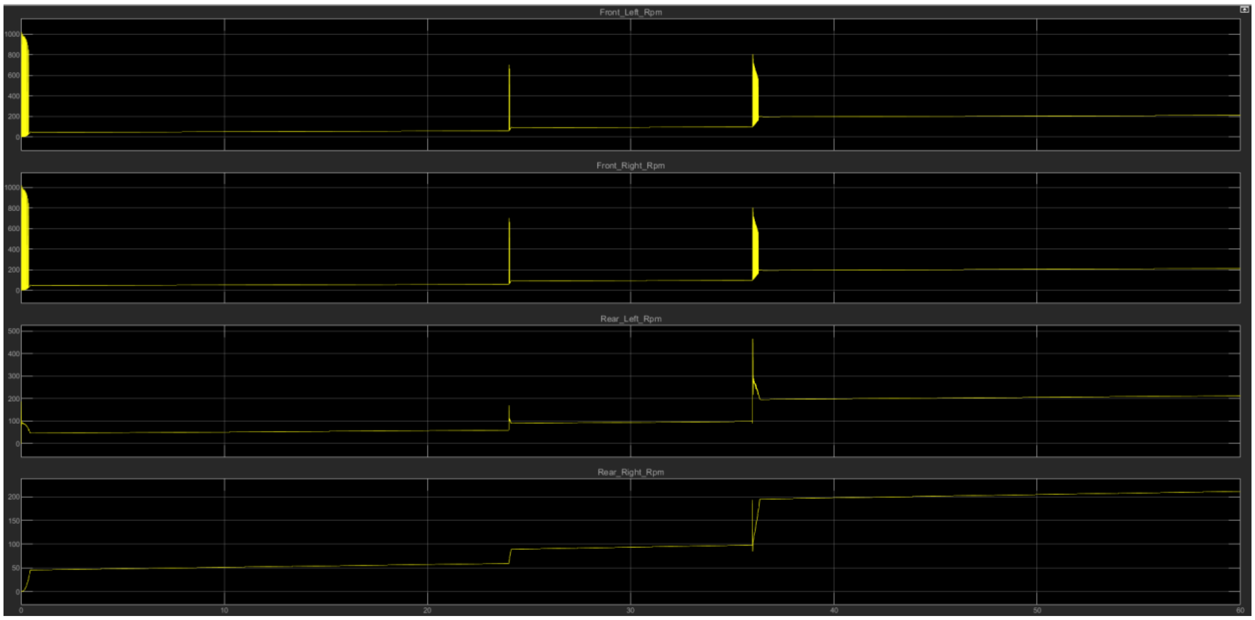


Figure 17 Wheel RPM

Comparison of with and without abs:

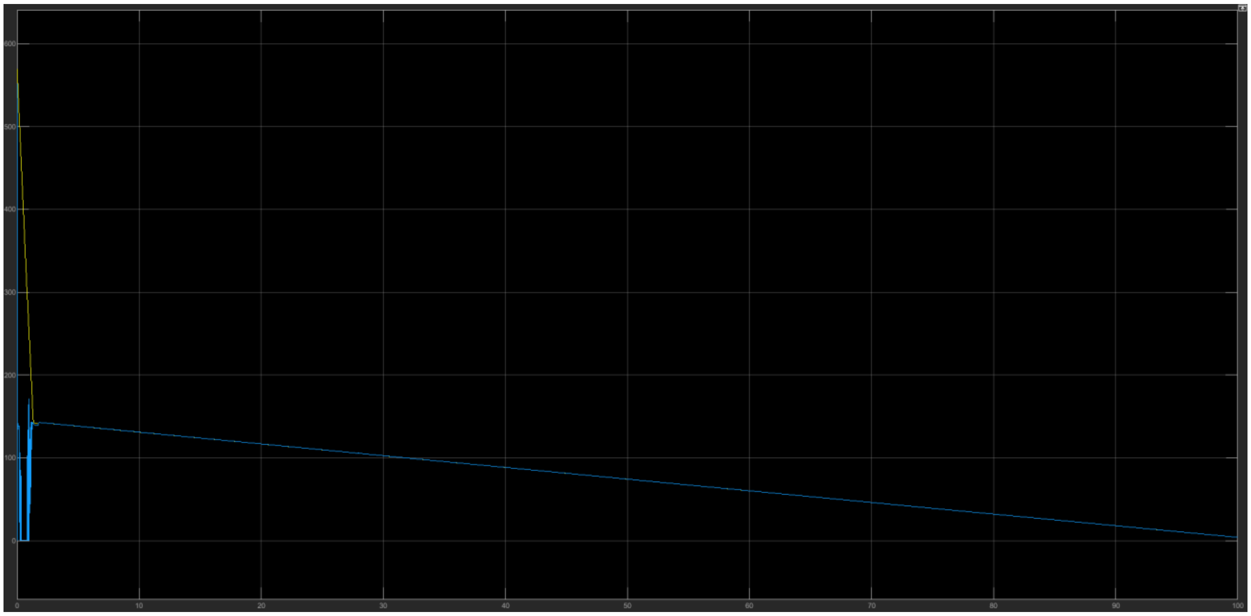


Figure 18 Vehicle Angular Speed Vs Wheel RPM (Traction and ABS on)

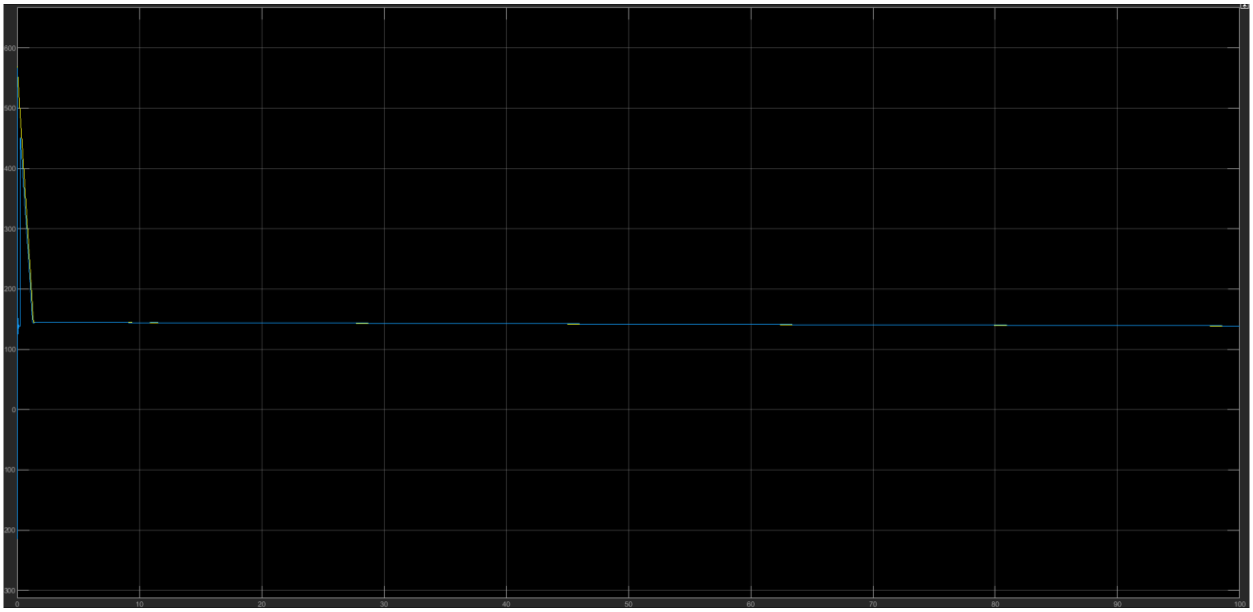


Figure 19 Vehicle Angular Speed Vs Wheel RPM (Traction and ABS off)

The scenario in this case is that the vehicle’s initial speed is about 60 km/hr and one side of the wheels are slipping due to less friction than the other wheels.

The result is that we get smooth and control deceleration of the vehicle without skidding when the traction control is on.

When the traction control is off, we get very haphazard deceleration and there is huge different in vehicle angular speed and wheel rpm i.e relative slip ratio.

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