Anti-Lock Brake system

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Anti-lock brake system

Mathematical modelling of ABS and simulation in MATLAB Simulink

1.1 Introduction

Anti-lock braking systems (ABS) are meant to **control the wheel slip** in order to maintain the friction coefficient close to the optimal value. Wheel slip is defined as the relative motion between a wheel (tire) and the surface of the road, during vehicle movement. Wheel slip occurs when the angular speed of the wheel (tire) is greater or less compared to its free-rolling speed. In order to simulate the braking dynamics of a vehicle, we are going to implement **simplified mathematical models** (quarter-car model) for both vehicle and wheel. Also, a simplified ABS controller is going to be implemented in order to emulate the braking torque in slip conditions.

1.2 Vehicle Model

If we consider the vehicle is moving in forward direction under braking condition. The equation of the system will be as follows.

$F_t = F_i$ (1)

$F_t \rightarrow friction\ force\ between\ wheel\ and\ ground$

$F_i \rightarrow inertia\ force\ of\ the\ vehicle$

$N = W$ (2)

$N \rightarrow Normal\ force\ of\ the\ vehicle$

$W \rightarrow weight\ of\ the\ vehicle$

$F_t = \mu . N$ (3)

$\mu \rightarrow friction\ coffecient$

$W = m_v . g$ (4)

$m_v \rightarrow mass\ of\ the\ vehicle$

$g \rightarrow accelaration\ due\ to\ gravity$

From equation 3 and 4

$F_t = \mu . m_v . g$ (5)

Inertia force

$$F_i = m_v . a_v = m_v . \frac{dv_v}{dt}$$

$\frac{dv_v}{dt} = \frac{1}{m_v}(\mu . m_v . g)$ (6)

Vehicle velocity is obtain by integration the equation 6. Limit equation.

1.3 Wheel model

Wheel equation is shown as below.

$T_b - F_f . r_w - \frac{J_w d\omega}{dt} = 0$ (7)

Integrating above equation with limit give us angular velocity (rpm) of the wheel.

1.4 Wheel slip

ABS has to control the wheel slip. Below equation gives is the wheel slip.

$Wheel\ slip = 1 - \frac{\omega_w}{\omega_v}$ (8)

$\omega_w \rightarrow Angular\ velocity\ of\ the\ wheel$

$\omega_v \rightarrow Equivalent\ anguar\ velocity\ of\ the\ vehicle$

$\omega_v = \frac{V_v}{r_v}$ (9)

$V_v \rightarrow linear\ velocity\ of\ the\ vehicle$

$r_v \rightarrow radius\ of\ the\ wheel$

1.5 Coefficient of friction

- Coefficient of friction depends upon many factors like.
- Wheel slip

- Vehicle speed
- Type of road surface
- Environment conditions

For our simulation purpose and for simplification we will use lookup table, entries are as follows.

Coefficient of friction	slip
0.00	0.000
0.05	0.400
0.10	0.800
0.15	0.970
0.20	1.000
0.25	0.980
0.30	0.960
0.35	0.940
0.40	0.920
0.45	0.900
0.50	0.880
0.55	0.855
0.60	0.830
0.65	0.810
0.70	0.790
0.75	0.770
0.80	0.750
0.85	0.730
0.90	0.720
0.95	0.710
1.00	0.700

Table 1.0

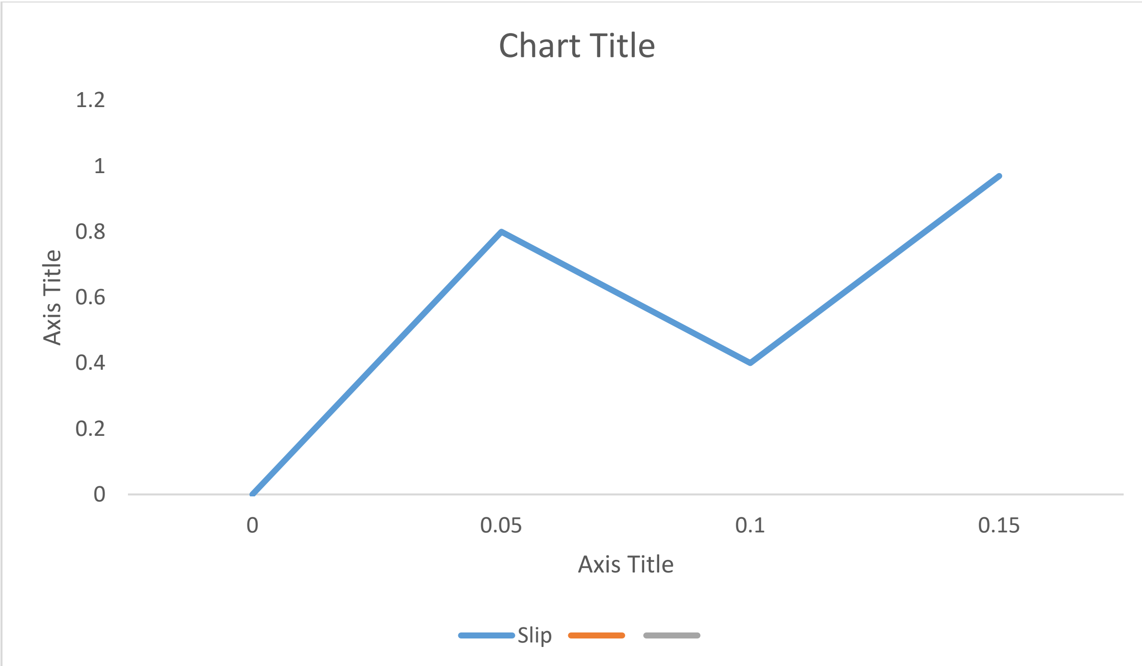

Fig – 1.1 Slip v/s Coefficient of friction

1.6 Model parameters

Symbol	unit	value	description
m_v	Kg	1200	Mass of the vehicle
J_w	$Kg.m^2$	6	Moment of inertia of the wheel
r_w	m	1.25	Radius of the wheel
V_0	$\frac{m}{s}$	44	Initial velocity of vehicle before braking
g	m/s^2	9.81	Acceleration due to gravity

Table – 1.2

1.7 Simulation in MATLAB-Simulink

Final Model obtain after modelling above equation and model parameters.

Problem 3 (300 points)

Design a complex automotive system of your choice. Create a small report of this project and demonstrate following skills in your model. Highlight these skills in your report.

1. Callbacks
2. Data Inspector
3. Solver selection strategy
4. MATLAB function block
5. Look-up table
6. Signal Builder to generate test signals. Demonstrate how your system is performing under various test conditions

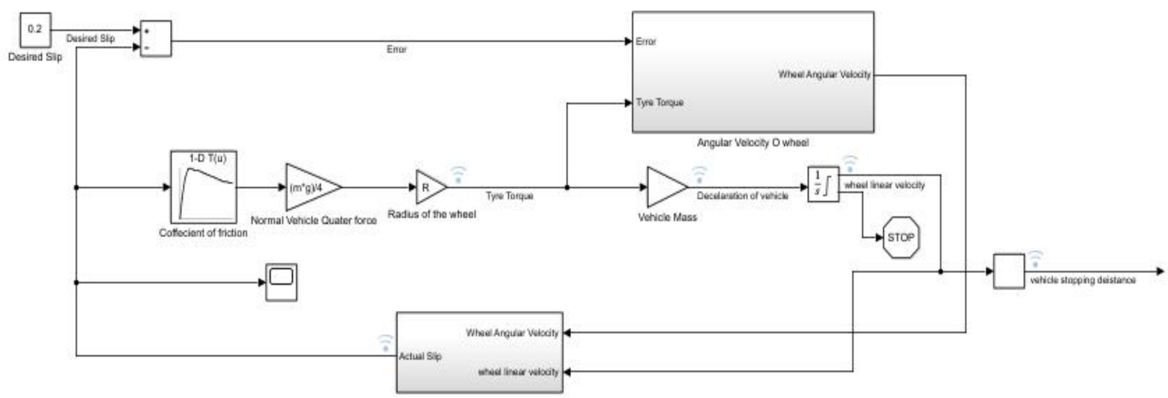

Fig 1.2 Block Model

Angular velocity of the wheel Block

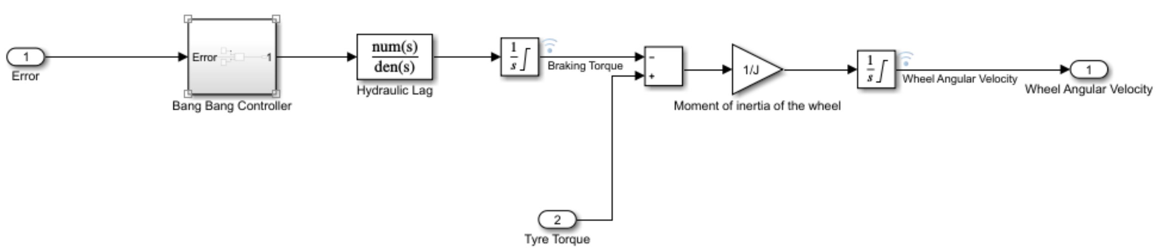

Fig – 1.3 Angular velocity of wheel

1. Bang-Bang controller
   If the input is greater than zero it gives output +1
   If the input is less than zero it gives output -1.
2. Hydraulic lag

This is the lag generated between pressing the brake paddle and actually brake being applied. This is simulated through arbitrary transfer function.

3. Integrator
   Integrating the output of the transfer function we get braking torque.
4. Difference between tyre torque and braking torque is the resultant torque moving the tyre.
5. Integrating the output with constant 1/Jw moment of inertia gives us wheel's angular velocity.

Tyre torque

Coefficient of friction from the lookup table.

$\frac{dv_v}{dt} = \frac{1}{m_v}(\mu \, . \, m_v \, . \, g)$ This equation is simulated in this section which produce tyre torque.

From tyre torque vehicle linear velocity if determined. Integrating the tyre torque with constant 1/m (mass of the vehicle) give us velocity of the vehicle and then multiplying it by 1/R gives us equivalent angular velocity of the vehicle.

Slip Calculation

$Wheel\, slip = 1 - \frac{\omega_w}{\omega_v}$ This equation is simulated to calculate the slip. Which is subtracted from desired slip to calculate the error which feed to the bang-bang controller.

OUTPUT

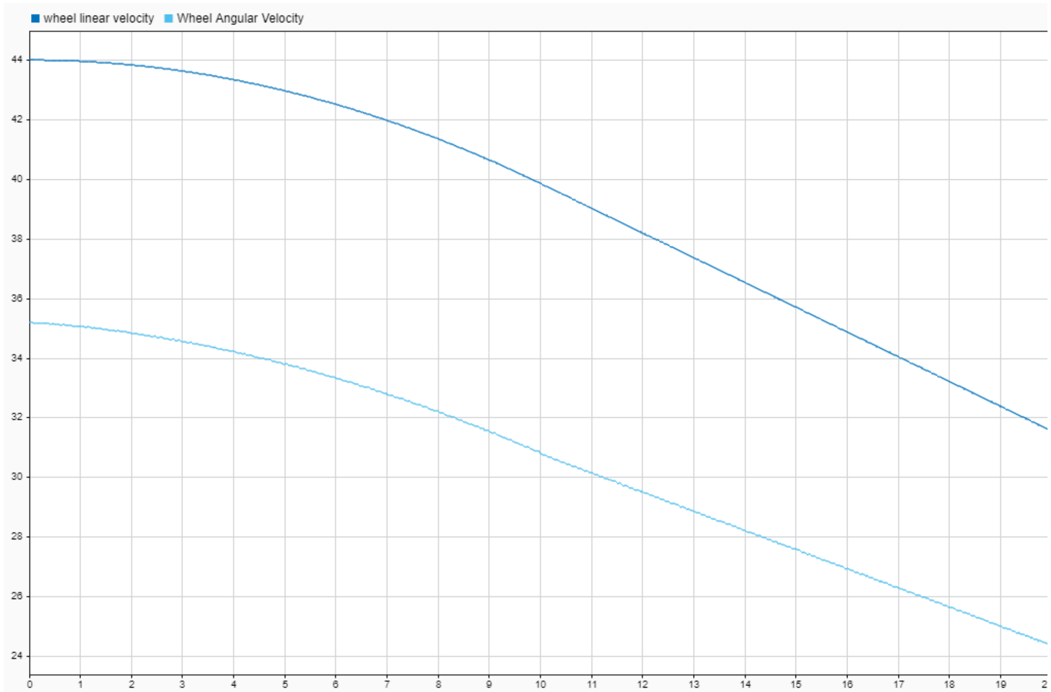

Fig 1.4 Wheel angular velocity and wheel linear velocity

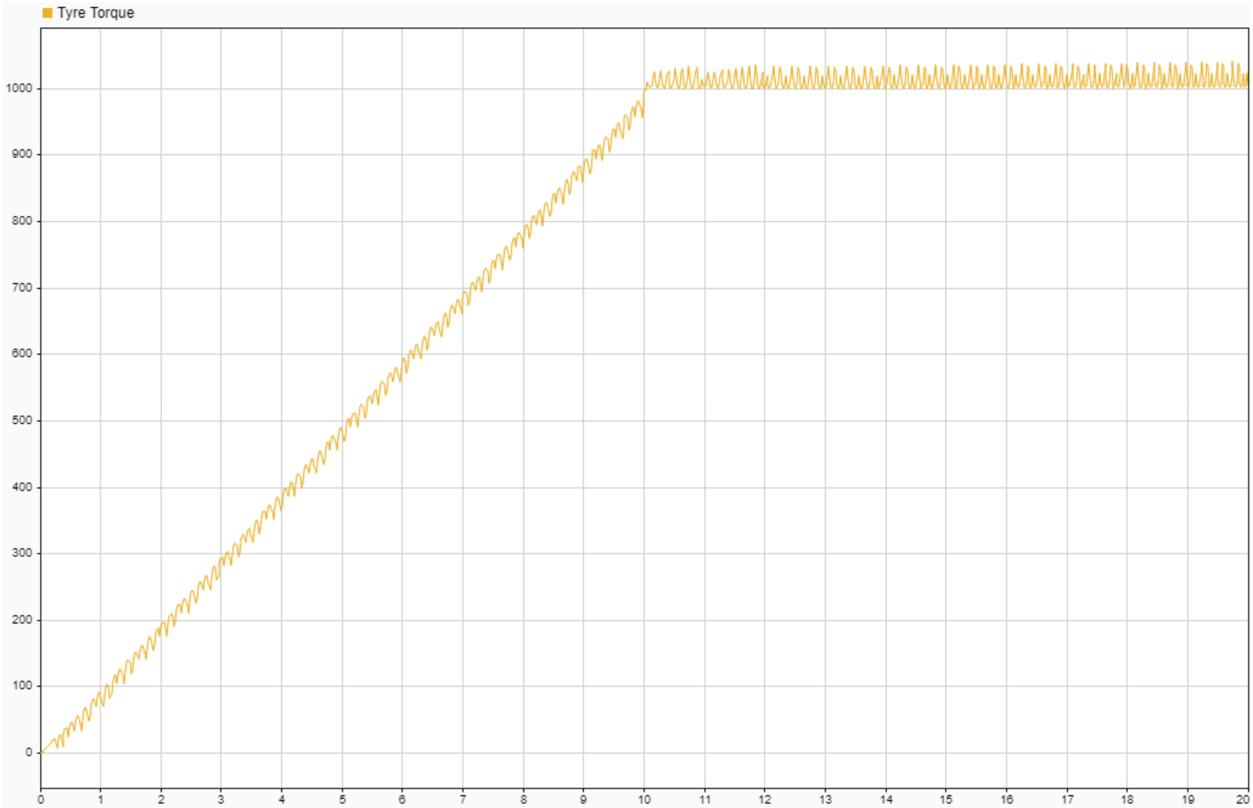

Fig 1.5 Tyre torque

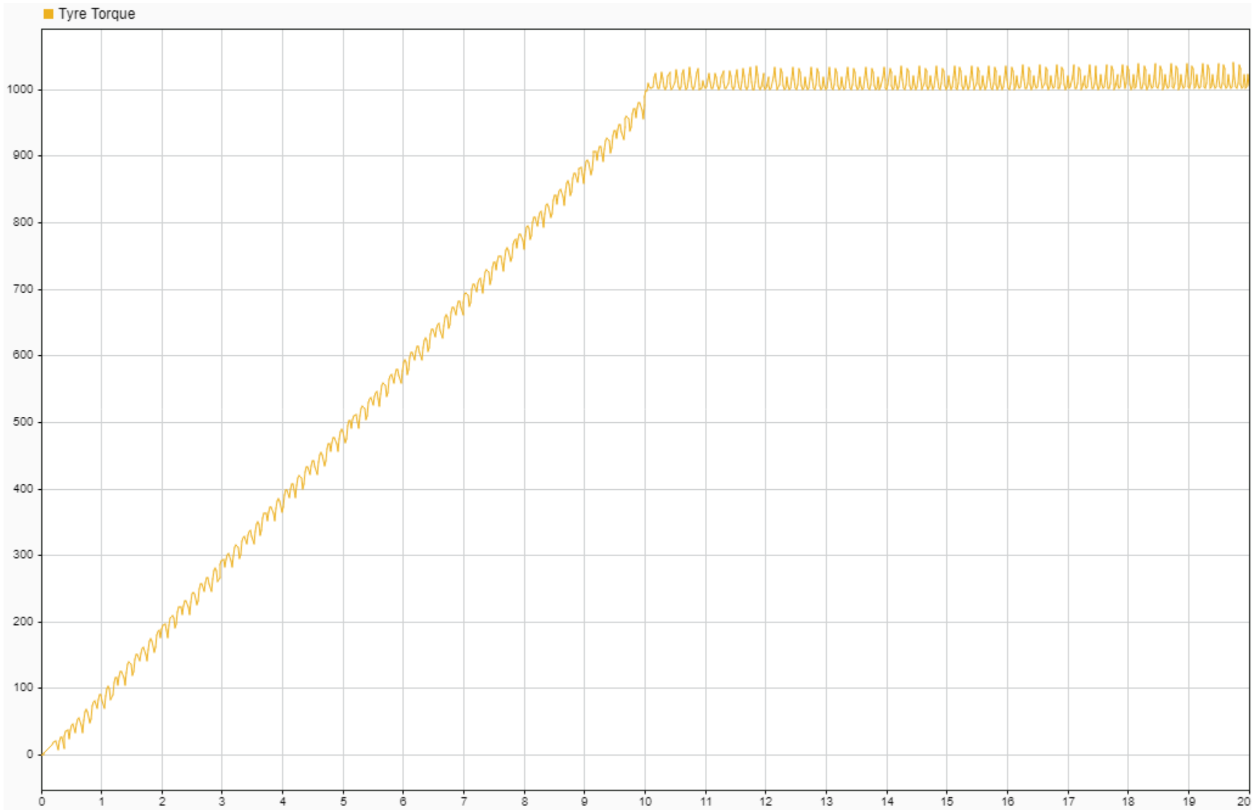

Fig 1.6 Braking torque

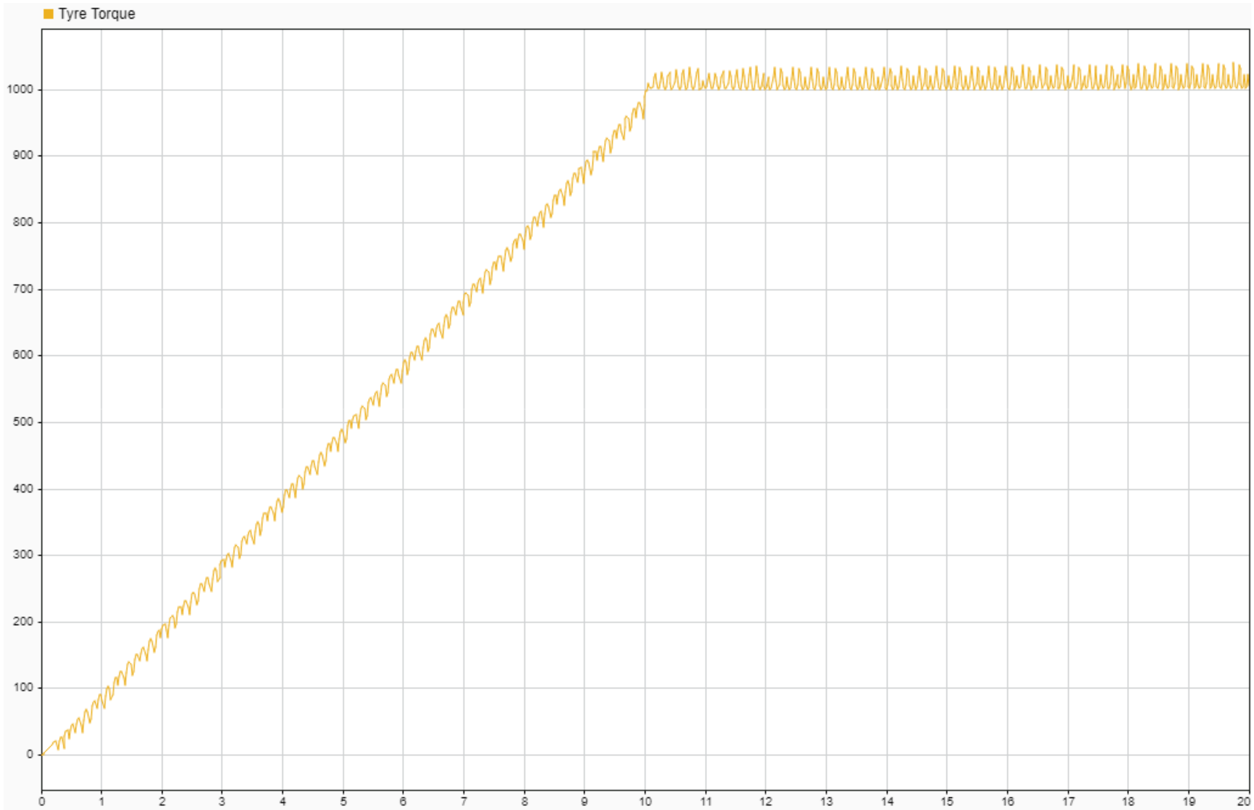

Fig 1.7 Deceleration of the vehicle

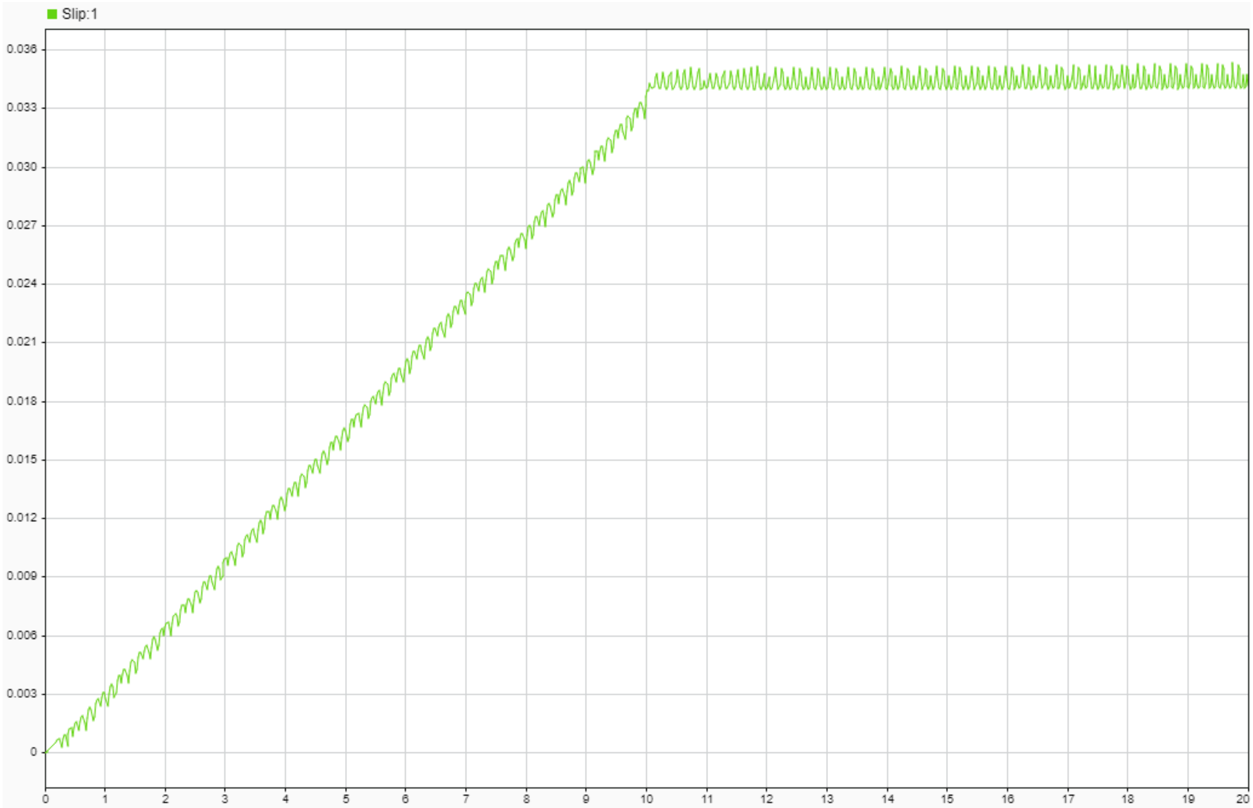

Fig 1.8 Slip of the wheel

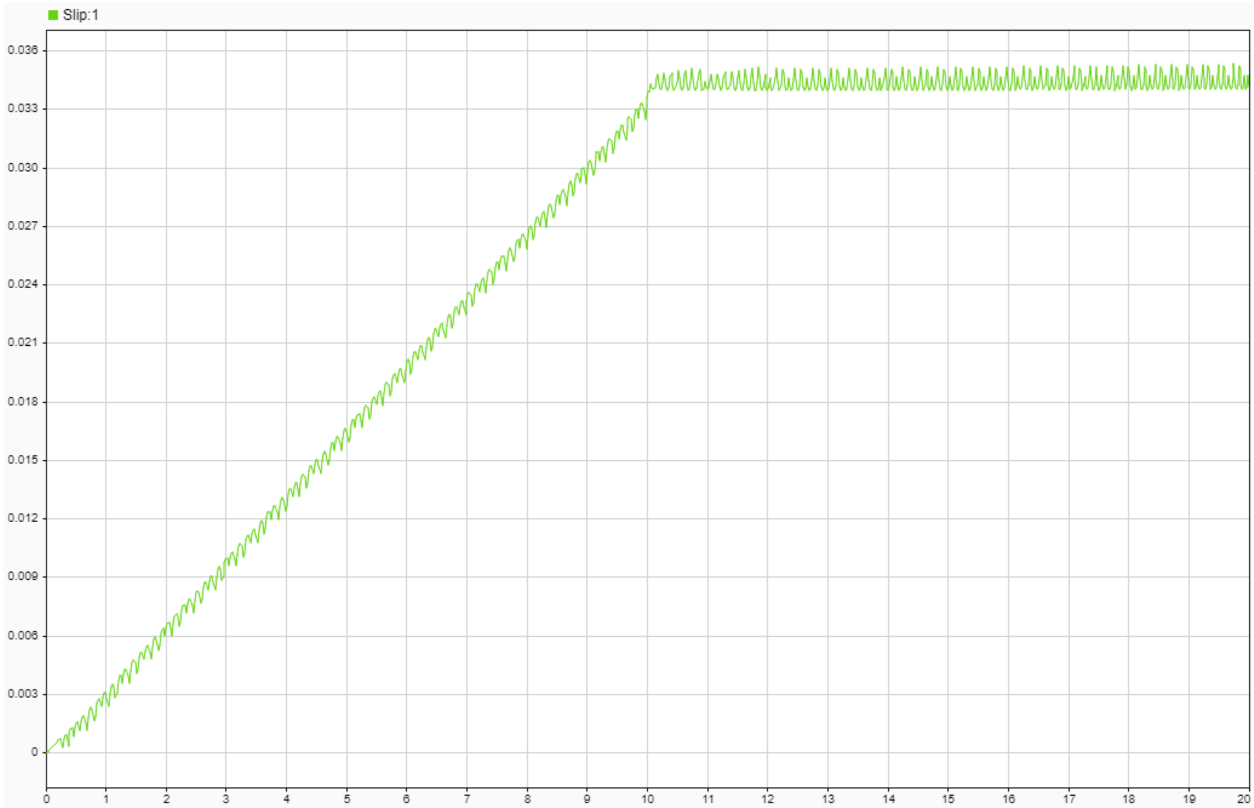

Fig 1.9 Stopping distance