REPORT FOR FUZZY LOGIC CONTROL SYNTHESIS FOR AN AIRPLANE ANTILOCK-BRAKING SYSTEM

As a project work for course

INT246 :: SOFT COMPUTING

Name :: Regved Pande

Registration Number :: 11902027

Project (Category) :: Individual

Program :: BTech CSE

Semester :: Third

School :: School of Computer Science and Engineering

Name of University :: Lovely Professional University

Date of Submission :: 11th November 2021

TABLE OF CONTENTS

INTRODUCTION

- In principle, in the ABS brake, the control is considered from a “panic stop” viewpoint the ABS is designed to stop the vehicle as safely and quickly as possible. This means first of all the avoiding of the vehicle lateral instability as a result of wheel slip increasing beyond a critical point, where the ability to steer the vehicle will be compromised.

- The cause is not the loss of longitudinal friction coefficient, but the lateral friction coefficient, which decreases proportional to the slip. Given the ABS’s main purpose, the controller releases or applies the brakes, aiming to achieve a tradeoff between braking effectiveness and lateral stability.

AIRPLANE BRAKE MATHEMATICAL MODEL

- The controlled system is represented by the
  - Main wheels
  - Rear wheels

- The motion dynamics arising from the rotation of the vehicle about the vertical axis, or from uneven braking forces applied on wheels, are not considered. The straight-line braking maneuver holds on horizontal road. Thus, the lateral tire forces are neglected; the effects of pitch and roll are also neglected.

- When the airplane is braking or accelerating, the tractive forces Ff , Frl, Frr, developed by the road on the tire, are proportional to the normal forces Z1 and Z2l = Z2r = Z2 of the road acting on the tire, as illustrated in Fig. 1: Ff = φZ1, Frl = φl Z2, Frr = φr Z2.

- In the above, by Ff, Frl, Frr were denoted the front, the left rear and the right rear tractive forces; φ is the road adhesion coefficient at front wheel; φl, φr are the road adhesion coefficients at rear wheels. The coefficient φ is taken constant and the coefficients φl, φr are functions of the wheel slip α and depend, as parameters, on the airplane velocity v and the road conditions c: dry, wet or ice.Thus,

φl := φl (α; v, c), φr := φr (α; v, c).

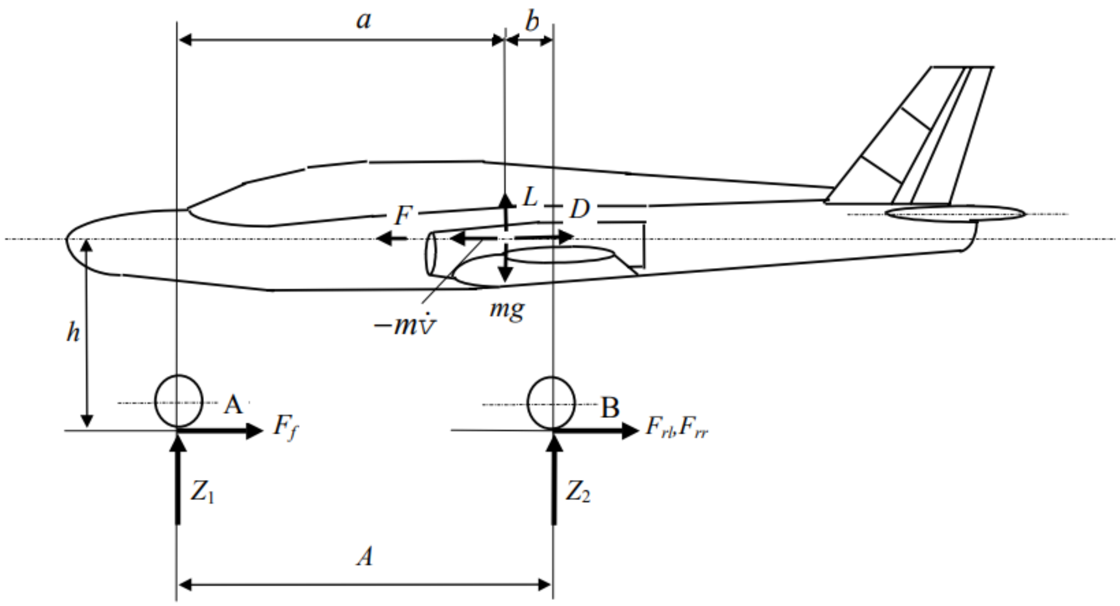


Fig. 1 – Sketch of the forces developed during the airplane braking

Considering the Newton's second law along the horizontal axis, the moments about the contact points A, B of the tire and the front and rear wheel dynamics, respectively, gives

$$
\begin{gathered}
-m\dot{v} = (\omega_l + \omega_r)Z_2 + \varphi Z_1 - F + D \\
-m\dot{v}h + 2Z_2A - mga + aL + (F-D)h = 0, \quad -m\dot{v}h - Z_1A + mg(A-a) - (A-a)L + (F-D)h = 0 \\
-I\dot{\omega}_l - M_{bl} + \varphi_l Z_2 R = 0, \quad -I\dot{\omega}_r - M_{br} + \varphi_r Z_2 R = 0 \\
D = \rho S C_D v^2/2, \quad L = \rho S C_L v^2/2
\end{gathered} \tag{1}
$$

where: m – total mass of the airplane; F – thrust; D – drag; L – lift; ρ – air density; C_D – drag coefficient;

C_L – lift coefficient; S – wing area; h – height of the airplane sprung mass; A – distance between front wheel and rear axle; g – acceleration due to gravity; a – distance from center of gravity to front landing gear's wheel; b – distance from center of gravity to (rear) landing gear's axle; I – moment of inertia of the each rear wheel; R – radius of tire; ω_l, ω_r – angular velocities of the left and, respectively, right rear wheels; M_{bl}, M_{br} – left and, respectively, right rear wheel brake torques.

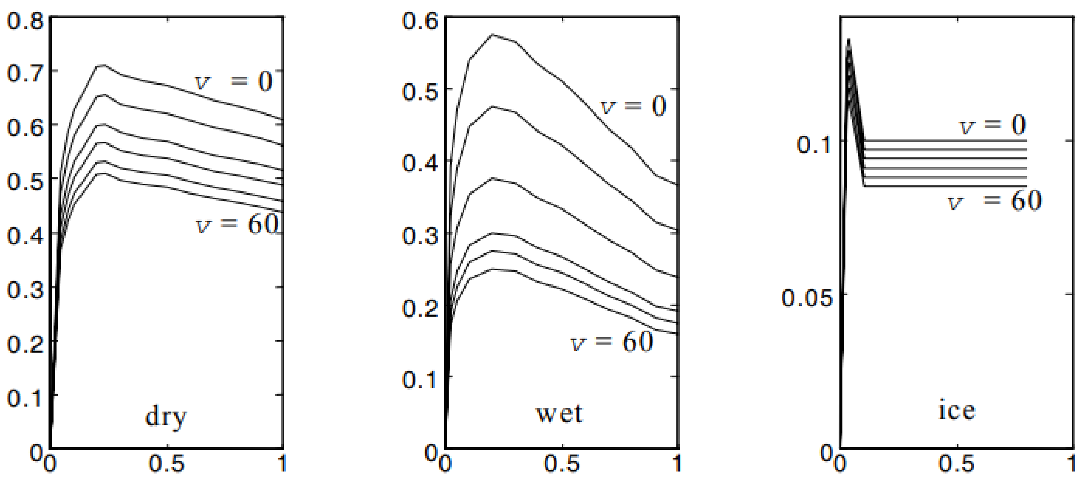


Fig. 2 – Parametric dependencies of road adhesion coefficients: $\varphi_l(\alpha; v, c)$, $\varphi_r(\alpha; v, c)$.

Solving for Z_1 and Z_2 the first three equations of the system (1), one obtains

$$\dot{v} = -\frac{(\varphi_l + \varphi_r)Z_2 + \varphi Z_1 - F + D}{m}, \quad \dot{\omega}_l = (\varphi_s Z_2 R - M_{bl})/I, \quad \dot{\omega}_r = (\varphi_r Z_2 R - M_{br})/I \tag{2}$$

$$Z_1 := \frac{(mg-L)[2(A-a) + (\varphi_l + \varphi_r)h]}{2(A - \varphi h) + (\varphi_l + \varphi_r)h}, \quad Z_2 := \frac{(mg-L)(a - \varphi h)}{2(A-\varphi h) + (\varphi_l + \varphi_r)h}. \tag{2'}$$

Thus, performing the numerical integration, the wheel slips are defined as

$$\alpha_l = \frac{v - \omega_l R}{v}, \quad \alpha_r = \frac{v - \omega_r R}{v}. \tag{3}$$

- Without braking, $v = \omega R$ and, therefore, $\alpha = 0$. In severe braking, it is common to have $\omega = 0$ while $v \neq 0$, or $\alpha = 1$, which is called wheel lockup. The brake proportionality constant kb relates, via the relations

$$M_{bl} = k_b P_l, \quad M_{br} = k_b P_r \tag{4}$$

the torques M_{bl}, M_{br} on the one hand, and pressures P_l, P_r in brake cylinders, on the other hand. The following first order linear differential equation was considered representative for the valve-brake cylinder system

$$\tau_{bc}\dot{P}(t) + P(t) = k_p u(t), \quad u(t) = u_k, \quad kT \le t \le (k+1)T, \quad k = 1, 2, \dots \tag{5}$$

where k_p is a proportionality ratio $P_{\max}/u_{\max}$, P is the pressure in brake cylinder, u is the control variable (current to servovalve), τ_{bc} is time constant of brake cylinder and k is the step of control insertion; the pressures P_l and P_r are thus the following solutions of the equations (5)

$$P_w(t, k+1) = e^{-(t-kT)/\tau_{bc}} P_{w,k} + \left(1 - e^{-(t-kT)/\tau_{bc}}\right) k_p u_{w,k}, \quad kT \le t \le (k+1)T, \quad k = 0, 1, \dots, w = l, r. \tag{6}$$

Index w marks the *l*eft or *r*ight wheel. Initial control values $u_{w,0} = u^*$, $w = l, r$, are given on $0 \le t \le T$; also, the initial pressures $P_{w,0} = 0$, $w = l, r$ are settled at $k = 0$. The constant pressures $P_{w,k}$ are given by recurrence equations

$$P_{w,k} = e^{-T/\tau_{bc}} P_{w,k-1} + \left(1 - e^{-T/\tau_{bc}}\right) k_p u_{w,k-1}, \quad k = 1, 2, \dots \tag{7}$$

because $P_{w,k}$ are defined by continuous evolution of pressures as

$$P_{w,k} =: P_w(t,k)\big|_{t=kT}, \quad k = 1, 2, \dots . \tag{8}$$

In defining the road adhesion coefficients φ_l, φ_r, three road conditions c were considered as representative for the road conditions: dry, wet and ice. The graphic functions $\varphi_l(\alpha; v, c)$, $\varphi_r(\alpha; v, c)$ were assumed from table representations given in reference [15] and are shown as interpolated versions in Fig. 2. These functions represent an extended Pacejka model [6] for longitudinal braking, which takes into account the decreasing of road adhesion coefficients by about 50 – 60% as the velocity v increases from 0 to 60 m/s.

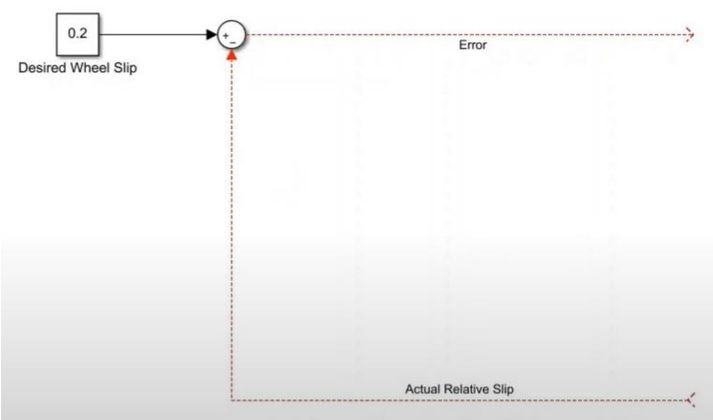
ANTI LOCK BRAKING SYSTEM WITH MATLAB AND SIMULINK

Let us understand the working mechanism of Airplane Anti Lock Breaking System Simulation with the help of MATLAB and SIMULINK, for example : An Airplane vehicle is to decelerate from a speed of 44m/s to standstill without wheel locking, the coefficient of friction between the tyres and the road is known. The desired wheel slip is 0.2 find the vehicle speed and slip over time, and the stopping distance.

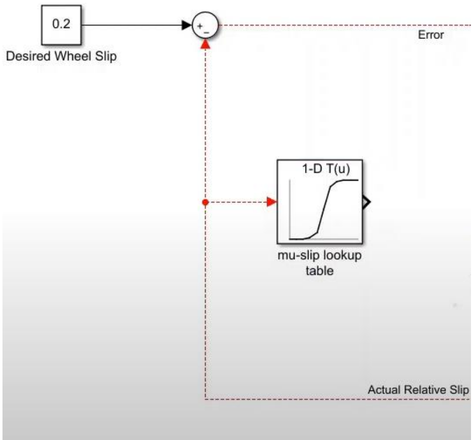
Step 1 :: First we set the desired wheel slip (0.2 will be the desired wheel slip)

Step 2 :: Then we can use summing joint for calculating difference and connect it to desired wheel slip

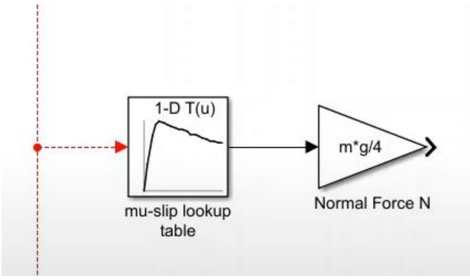
Step 3 :: We have calculate the actual wheel slip now output of these will be Error between Desired and Actual wheel slip.



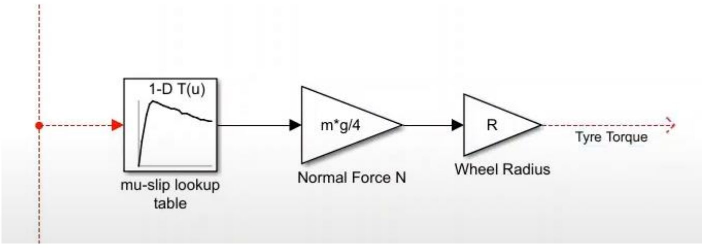
Step 4 :: For Actual Relative Slip we will be calculating both wheel angular velocity and vehicle angular velocity now to calculate wheel angular velocity and vehicle speed we will be needing the coefficient of friction between the tires and the ground so it will be changing as the wheel slip changes so we have a 1D lookup table for this so we will be attaching the input to the actual wheel slip, so it will output the coefficient of friction.



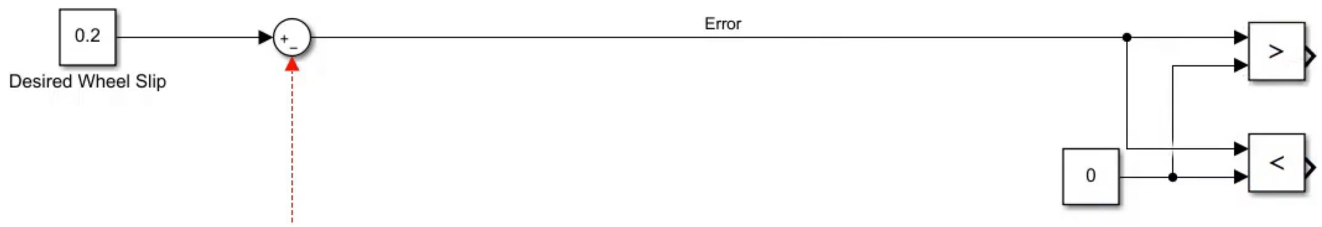
Step 5 :: Now we can add a gain block and it will be normal force of mg/4 and it can get multiplied by coefficient of friction.



Step 6 :: Now we can take another gain block with wheel radius R and the output is going to be the tyre torque.

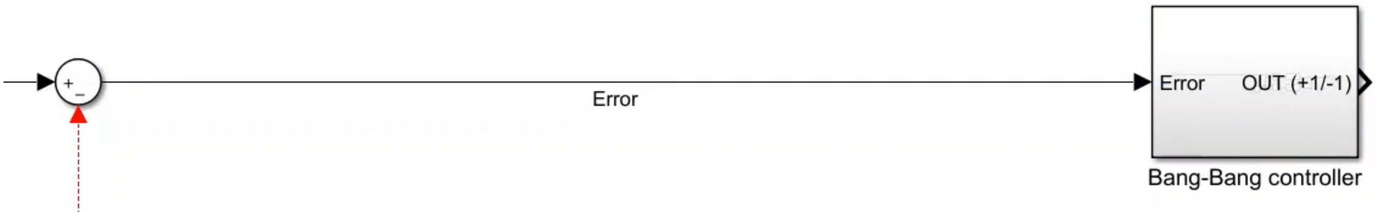


Step 7 :: Now we can use the tyre torque and error value to find wheel slip for this we need Bang-Bang controller (which output 1 if input is greater than 0 and -1 if less than 0) for this we will we using constant block for 0 as its value and then we will be using two comparison operators (>,<) with 0 as input for both and then we will be connecting error single to input of these block.



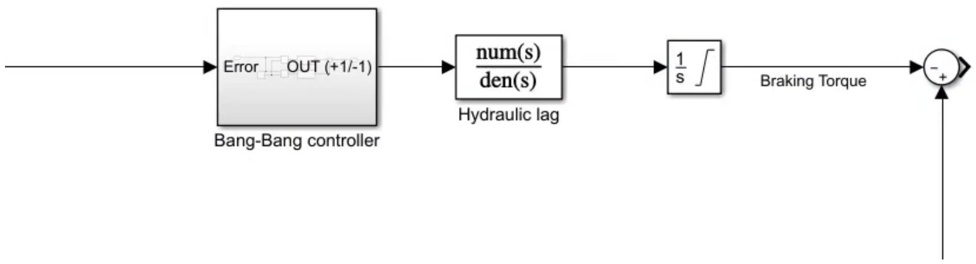
Step 8 :: After that we will be doing data conversion from integer to double and then we can add both of these to get desired result +1 for positive value and -1 for negative values.

Step 9 :: Now we can create a block of double and rename it to Bang Bang Controller.

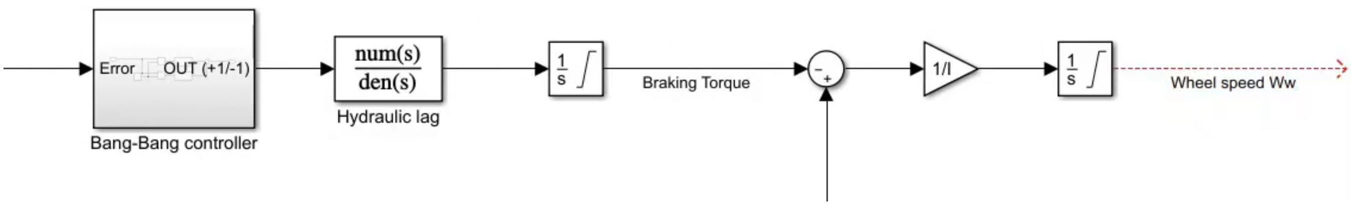


Step 10 :: After this we will be adding transfer function to the Bang Bang controller which represents the hydrolic lag once the break is applied now output of this function must be integrated over time to get the break force now output will be breaking Torque,

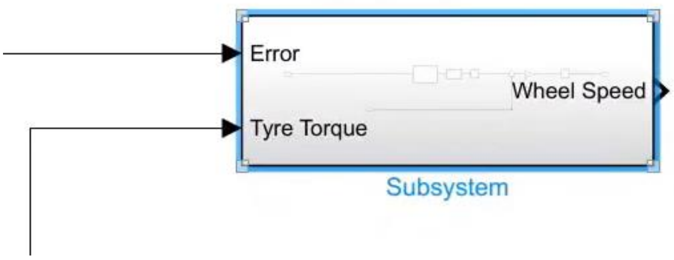
Step 11 :: Now we can compute the difference between the breaking Torque and the Tire Torque in order to compute the deacceleration of the vehicle so for this we will be adding the summing block for this we will be connecting breaking torque to negative and tire torque to positive.



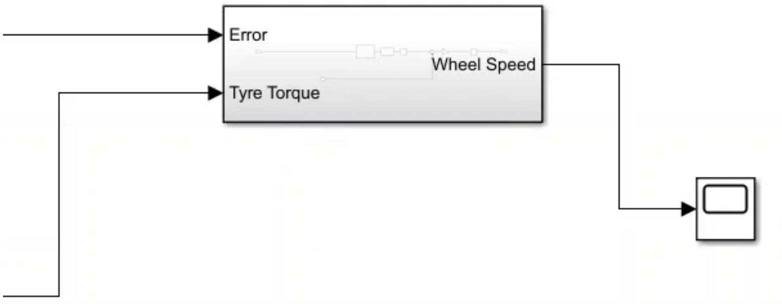
Step 12 :: Now we will divide it by moment of inertia in order to compute the acceleration for this we will integrating deacceleration to get the velocity of the wheel so it will be wheel speed.



Step 13 :: Now we can create the subsystem again and this block will take error signals and tyre torque as inputs and outputs the wheel speed

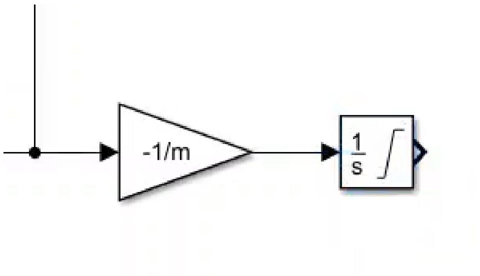


Step 14 :: **Afterwards we can connect wheel speed to scope so we can see readings after completing the simulations.**

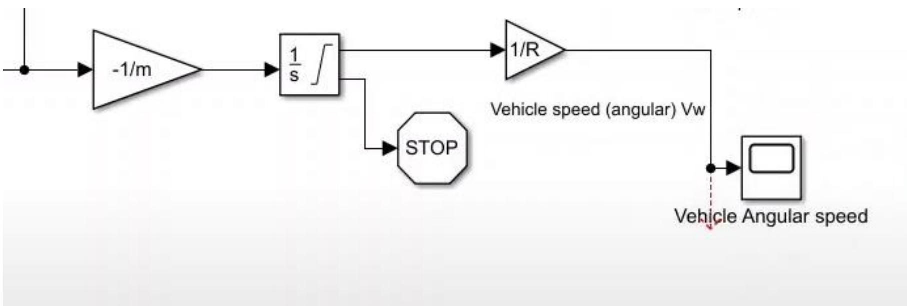


Step 15 :: **To find vehicle angular velocity we insert gain with value -1/m to show decelerating and m is the total mass of the vehicle now we can apply integral to find linear angular velocity and initial value of this will be the vehicle speed.**

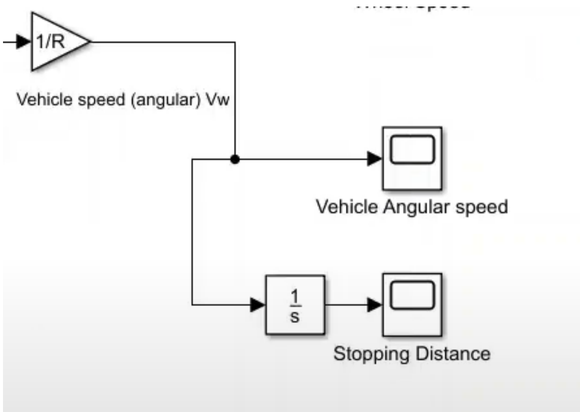
`



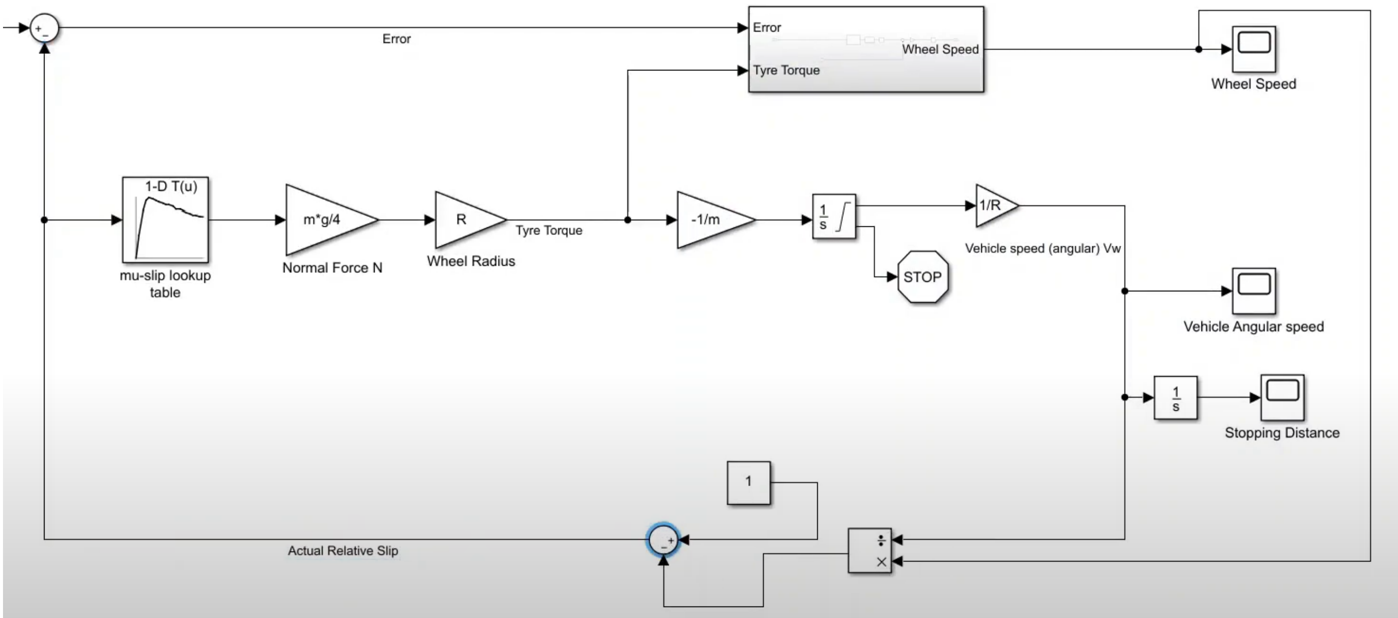
Step 16 :: **Now set wheel speed velocity to v0/r now to find equal angular velocity we should divide it by radius of the wheel and then we can connect a scope and measure it incase vehicle speed reaches 0 we need to stop the simulation so we will be connecting saturation port of the integral to the stop.**



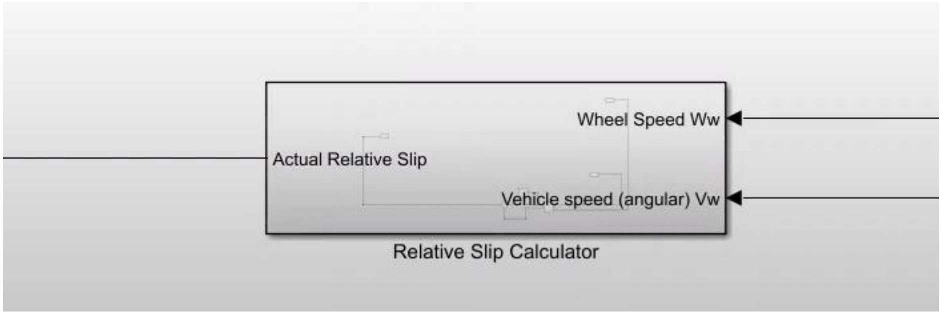
Step 17 :: Now we can calculate stopping distance from the vehicles speed for this we can do integration and we can connect to scope there once it's done we can find vehicles actual slip from the vehicle speed and wheel slip.



Step 18 :: To find vehicles actual slip from the vehicle speed and wheel slip for this we will be using divide block and we will be connecting product to the wheel slip and other one to the vehicle angular speed to compute relative slip we have to subtract this from 1 so we will be creating constant block of value one and then add summing block with negative sign and connect it to Actual Relative Slip.

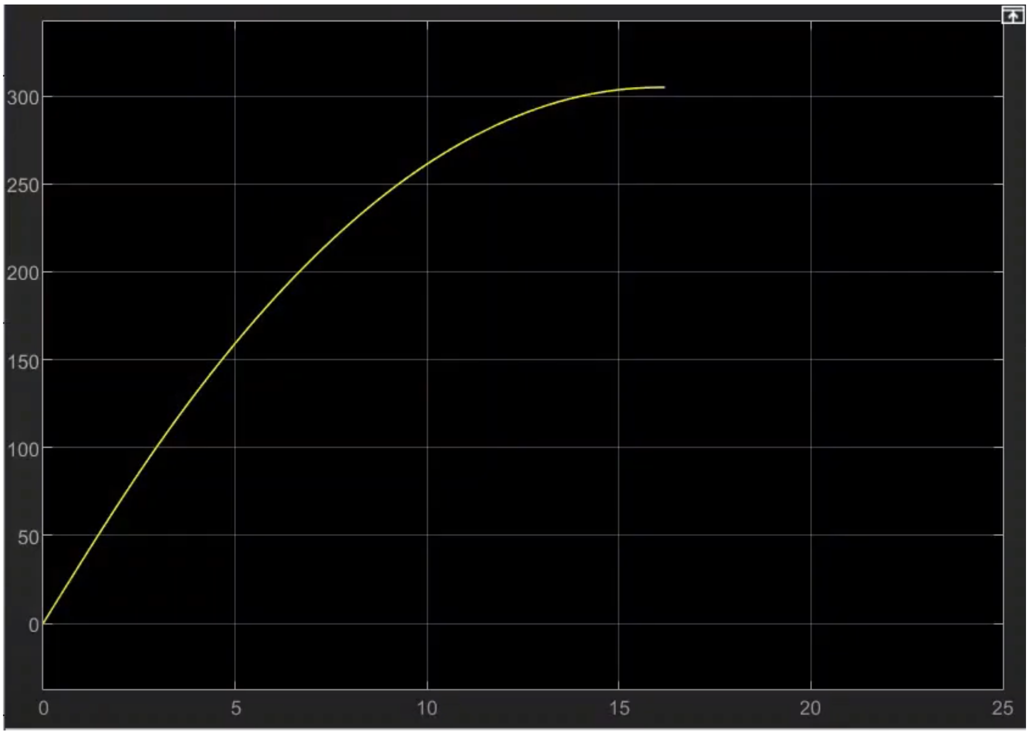


Step 19 :: Now Create Subsystem Block and name it Relative Slip Calculator



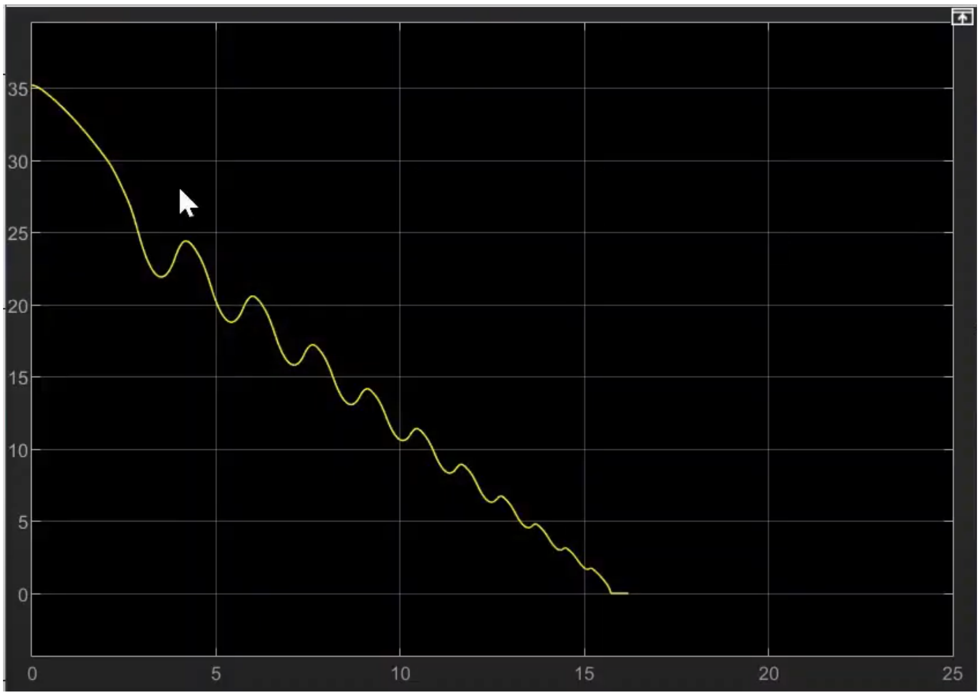
Step 20 :: After than we setup Simulation Time in MATLAB and Run it.

- **For Stopping System we get we get**

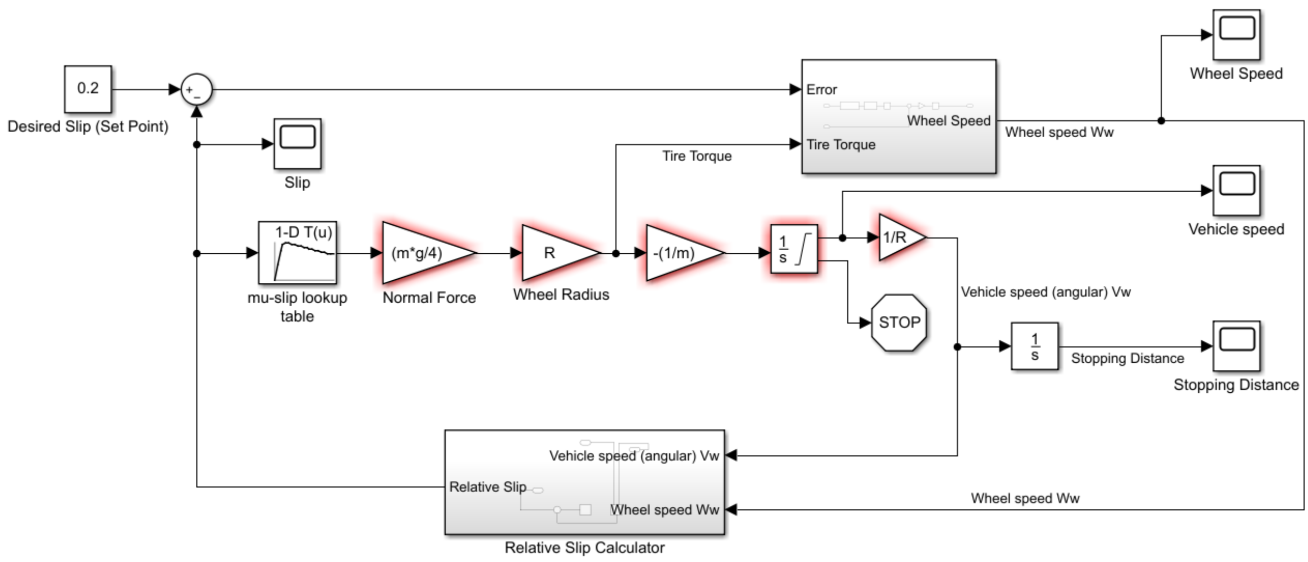


- **For Vehicle Angular Speed we get**

- **For Wheel Speed we get**



Final Output will be



Conclusion

Let finally note the most meaningful feature of the proposed ABS fuzzy logic controller: because is in fact a free model strategy, this methodology ensures a reduced design complexity and provides antisaturating and antichattering properties of the controlling system [13], thus favourising its robustness.

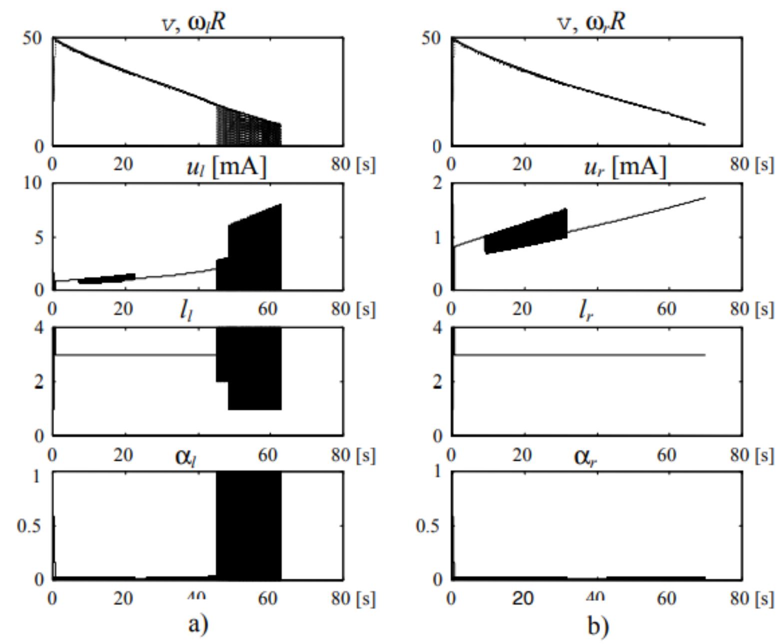


Fig. 7 – Braking evolution on ice; fuzzy control moderating parameters:
a) θ = 1/0.2, φ = 1. ; b) θ = 1/0.2, φ = 1/0.6.

REFERENCES

In order to initiate this project the following tools have been used

- **Matlab ::** https://in.mathworks.com/products/get-matlab.html?s_tid=gn_getml
- **Simulink ::** https://in.mathworks.com/products/simulink.html

Other References Include

1. LENNON, W. K., K. M. PASSINO, Intelligent control for brake systems, IEEE Transactions on Control Systems Technology, 7, 2, March 1999, pp. 188–202.

2. VAN ZANTEN, A., G. HESS, H. P. GEERING, Method for ascertaining the set point braking moment for the various wheels of a vehicle, US Patent No. 4, 679, 866, July 14, 1987.

3. DRAKUNOV S., U. OZGÜNER, P. DIX, B. ASHRAFI, ABS control using optimum search via sliding modes, Proceedings of the 33rd Conference on Decision and Control, Lake Buena Vista, FL, Dec. 1994, pp. 466-471.

4. KITAJIMA, K., H. PENG, H∞ control for integrated slide-slip, roll and yaw controls for ground vehicles, Proceedings of AVEC 2000, 5th International Symposium an Advanced Vehicle Control, Ann Arbor, Michigan, August 24, 2000.

5. ŰNSAL, C., P. KACHROO, Sliding mode measurement feedback control for antilock braking systems, IEEE Transactions on Control Systems Technology, 7, 2, March 1999, pp. 271-281

6. MAUER, G. F., A fuzzy logic control for an ABS braking system, IEEE Transaction on Fuzzy Systems, 3, 4, November 1995, pp. 381-388.

7. BUCKHOLTZ, K. R., Use of fuzzy logic in wheel slip assignment-Part I: Yaw rate control; Part II: Yaw rate control with sideslip angle limitation. SAE Technical Paper Series, 2002, No. 2002-01-1220. Reprinted from: Vehicle Dynamics and Simulation, 2002 (SP-1656).

8. WANG, L., Adaptive fuzzy systems and control − design and stability analysis, Englewood Cliffs, New Jersey, Prentice Hall, 1994.

9. YEN, J., R. LANGARI, L. A. ZADEH EDS., Industrial applications of fuzzy control and intelligent systems, New York, IEEE Press, 1995

10. VLADIMIRESCU, M., F. POPESCU, I. URSU, Method for deriving a quasi-optimal regulator for an ABS type system (Antilock breaking system for vehicle using wheels), 25th International Congress of Mathematicians, Zürich, August 3-11, 1994.