Indian Institute of Technology Madras

Engineering Design Department

ED 5220 – Vehicle Dynamics Tutorial/Lab

Jan - May 2024

Assignment–2: Longitudinal Dynamics

Date: Sun, 24 March 2024	**Due Date**: Wed, 03 April 2024 11.59 pm

Instructions:

- *Solutions to be submitted ONLY moodle in .pdf files only. Each student should submit his/her individual set of solutions.*
- *Typed/scanned copy of written solutions are allowed. Graphs to be labelled, with axes titles and units.*
- *Solution file (.pdf) to be named as A<tutorial no>_<roll no.>. For example, week 1 session solution file of student be named as A1_ED20B000.pdf*
- Late submissions will NOT be entertained

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1. An automotive startup company hired one of our friends to design safety systems for passenger cars. Our friend's job requires him to design a controller that would not allow the vehicle to skid. The first stage of design to develop controller for quarter car model. Our friend was able to draw free-body diagrams but struggling with equations. Help our friend derive equations of motion. [10M]

   (a). Translational motion

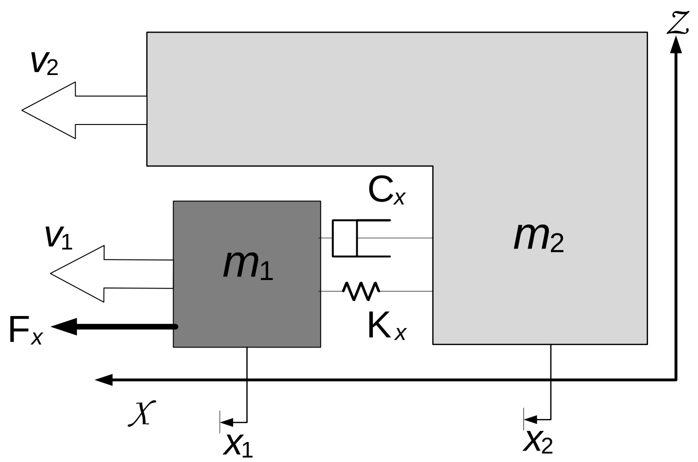

Figure 1 quarter car model

$\dot{x_2}$ is velocity of vehicle w.r.t ground (v_x)

(b). Rotational dynamics

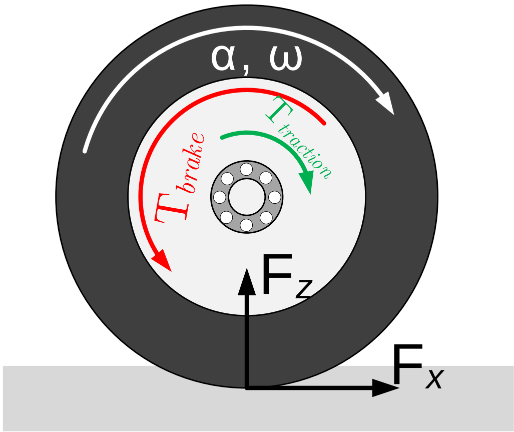

Figure 2 rolling tyre

The firm has provided him with different tyres to test his controller. The empirical model of the tyres are described by Magic Formula

$$y = \mu \sin[C \arctan(Bx - E(Bx - \arctan Bx))]. \tag{1}$$

$$Y(X) = y(x) + S_v \tag{2}$$

$$x = X + S_H \tag{3}$$

$$\mu = D.F_z \tag{4}$$

Y is Fx and X slip ratio
Slip ratio (λ) is defined as

$$\lambda = \frac{r_{eff}\omega - V_x}{V_x} \tag{5}$$

(a). Derive equations of motion

(b). Using the above equations plot Fx vs λ graphs for the given tyres. Overlap both figures. Graphically identify the slip ratio corresponding to each tyre, at which peak braking force can be obtained. This is region of operation of your controller.

(c). Design a suitable controller such that braking torque, $\tau_B(t)$ maintains slip in close vicinity of slip found in (b).
Relation between brake pressure and brake torque for a disc brake is given by

$$\tau_B(t) = \frac{\mu\pi D^2 R_m N}{4} P_B(t) \tag{6}$$

(d). For each of the tyres plot and report the following. Overlap figures for both cases of tire changes, i.e., 2 rows x 4 columns grid with each subplot having overlapped figures.

- Fx vs time (figure)
- Slip vs time (figure)
- Fx vs slip (figure)
- Histogram of slip (figure)
- a_x vs time (figure)
- Brake torque vs time (figure)
- Vx and $\omega.r_{eff}$ vs time on same plot (figure)
- Stopping distance (value) – distance calculated from instant brake is applied to instant vehicle reaches stopping speed Vs
- Stopping time (value) – time elapsed from instant brake is applied to instant vehicle reaches stopping speed Vs.

Compare the results and state your observations

Table 1 List of Tire parameters

Tire	B	C	D	E	S_H	S_V
1	11.48	1.3	1.055	-2	2.98e-5	-0.0028
2	16.5	1.6	1.084	-0.5	2.98e-5	-0.0028

Table 2 parameters list

parameter	units	value
m1 (unsprung mass)	Kg	35
m2 (sprung mass)	Kg	300
r_{eff}	m	0.35
R1 (rate of inc. of brake pressure)	bar/s	200
R2 (rate of dec. of brake pressure)	bar/s	800
R_m (Brake pad radius)	m	0.15
D (Brake cylinder bore)	m	0.057
μ (Brake friction coeff)	-	0.5
N (number of brake pads)	-	2
V_{x0} (initial velocity)	m/s	27.78
V_s (stopping velocity – stop simulation)	m/s	0.5
Ip (rotational inertia of wheel)	$Kg.m^2$	0.8
C_x	N/(m/s)	200
K_x	N/m	100000

Any other parameters not mentioned here can be assumed with appropriate reasoning and to be mentioned in your submission.

2. Being reasonably satisfied with quarter car model, your friend's manager wants to take the simulation a step ahead adding more details to the plant model. Construct a longitudinal half car model, i.e., cut the car along its x-z plane. To simplify the relatively complicated model, you can utilise MBD solver. Use the TIR file provided for tire simulation. Design ABS controller for the half car model. Required parameters are given. Any other parameters not mentioned here can be assumed with appropriate reasoning and to be mentioned in your submission. [10M]

What parameters of brakes would you change and to how much, to achieve better ABS performance. Explain with simulation results.

Table 3 parameters list

	parameter	**units**	**value**
vehicle	m (sprung mass)	Kg	600
	I (sprung mass inertia)	Kgm^2	[600,600,600]
	[a1,a2] (distance of CG to axles)	m	[1,1.5]
	k1, k2 (suspension stiffness)	N/m	3e4
	c1, c2 (suspension damping)	N/(m/s)	2e3
	Ip (rotational inertia of wheel)	$Kg.m^2$	[1,1,1]
	m1, m2 (mass of unsprung mass)	kg	20
brake	R1 (rate of inc. of brake pressure)	bar/s	200
	R2 (rate of dec. of brake pressure)	bar/s	800
	R_m (Brake pad radius)	m	0.15
	D (Brake cylinder bore)	m	0.057
	μ (Brake friction coeff)	-	0.5
	N (number of brake pads)	-	2
sim	V_{x0} (initial velocity)	m/s	27.78
	V_s (stopping velocity – stop simulation)	m/s	0.5

Repeat parts (c) and (d) from above question. Additionally plot pitch and load acting on both axles.