INVESTIGATION INTO ROLLOVER PREVENTION USING ESC

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Abstract: This paper describes vehicle's roll dynamics and opportunities to prevent rollover and to increase lateral stability for buses. During aggressive steering maneuvers tire lateral forces may exceed certain thresholds. It may cause losing of control and as a result to rollover accident. To enhance dynamic stability and increase driver's and passenger safety high percent of manufacturers equips their vehicles with Electronic Stability Control (ESC) systems. Such systems have possibility to control lateral forces using brake system and controlling vehicle's traction and to prevent rollover. The paper contains review of vehicle's dynamic control systems, vehicle roll dynamics and its realization in MATLAB, simulation results and their analysis are considered.

Introduction

In comparison with passenger cars buses have a more elevated center of gravity. Because of this the rollover inclination is one of the main problems of such vehicle type. The Rollover Prevention (ROP) function is aimed to determine a critical situation and to prevent a rollover accident by regulating tire lateral forces which exceeded certain thresholds by using engine and brake controlling. This regulation is getting possible with using of ESC systems [1].

Following to NHTSA accidents statistics rollover accidents occurred only 3% of the whole accidents, but severity of injures is much higher in comparison with other types of accidents. There are 33% vehicles transported fatally injured occupants [2]. It became the main reason for researchers and manufacturers to pay attention to this problem, especially for vehicles with elevated center of gravity.

Tendentions

In recent days there are a lot of methodologies for prediction of rollover. As for example in [3] Young-Joo Cho proposes to use engine and brake control to prevent rollover, actually it means prevention by ESC. In this method the author proposes to use basic sensors of ESC and simplified roll-model with 2 degree of freedom. In [4] is proposed to use a "Rollover Index" which shows a rollover risk. Rollover also is investigated in [5] as three degrees of freedom vehicle model and characteristics according their effectiveness in rollover process are shown. Liebemann proposes [6] to use Rollover Mitigation Function which controls the rollover situation with the basic sensor of ESC. Thus it's one of the reasons for wide using of ESC on the different types of vehicles because it may help to solve the problem of rollover prevention.

Rollover model

The rollover model (figure 1) consists of two degrees of freedom with a vehicle's speed as an input data [7].

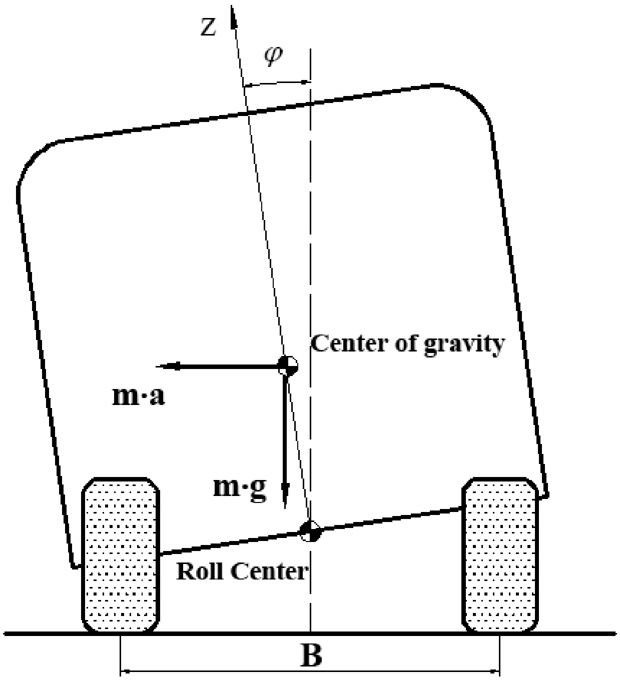

Figure 1: Roll model

Steering angles of wheels can be depicted as

$$\theta = \frac{\omega \cdot t}{U_{sg}} \tag{1}$$

Steering radius is equal as

$$R = \frac{L}{2 \cdot (ctg\theta_e + ctg\theta_i)} = \frac{L}{tg\theta} \tag{2}$$

Lateral acceleration is

$$a = \frac{v_0^2}{R} \tag{3}$$

Roll force is

$$F = m \cdot a \tag{4}$$

The model contains a non-linear pneumatic suspension to get more realistic results.

Roll force causes reactions in air spring elements is depicted as

$$F_{op} = \frac{2 \cdot h_g \cdot F}{B_p} \tag{5}$$

Their deformations equal

$$\Delta = z_l - z_{tl} \cdot \frac{B_p}{B} \tag{6}$$

Forces in pneumatic elements are determined by the formula

$$F_i = [p_1 \cdot (\frac{V_1}{V_i})^n - p_a] \cdot A_{ei} \tag{7}$$

The value of air spring in static position is

$$V_i = \frac{\pi \cdot D^2}{4} \cdot \Delta_{com} + \frac{\pi \cdot (D^2 - d^2)}{8} \cdot \Delta_{\exp} + \frac{\pi \cdot (D - d^2)(D + d)}{64} - \frac{\pi \cdot (D^2 + d^2)}{8} \cdot \Delta_i \quad (8)$$

Conditionally the road is absolutely smooth. Therefore tire forces are

$$F_{tl} = c_t \cdot z_{tl} \quad (9)$$

Accelerations of sprung and unsprung mass can be depicted as

$$a_l = \frac{2((-F - R_l - F_{op})}{m_0} \quad (10)$$

$$a_{tl} = \frac{2 \cdot ((F_l + R_l) \cdot \frac{B_p}{B} - F_{tl})}{m_0} \quad (11)$$

Displacements and velocities of sprung and unsprung mass can be determined as

$$v_l = v_0 + a_l \cdot dt \quad (12)$$

$$v_{tl} = v_{t0} + a_{tl} \cdot dt \quad (13)$$

$$z_l = z_0 + v_0 \cdot dt + \frac{a_l \cdot dt^2}{2} \quad (14)$$

$$z_{tl} = z_{t0} + v_{t0} \cdot dt + \frac{a_{tl} \cdot dt^2}{2} \quad (15)$$

As a result rollover angle is determined

$$\varphi = \frac{1}{B_p}(z_l - z_r) + \frac{1}{B_p}(z_{tl} - z_{tr}) \quad (16)$$

Simulation results

The simulation was performed at speed 60kmh on a dry smooth surface with high friction coefficient. For a provided test (fig. 2) graphical results are shown on the fig. 3.

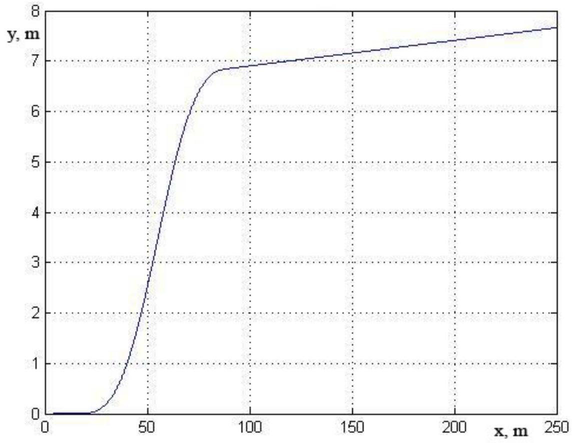

Figure 2: Trajectory (meters)

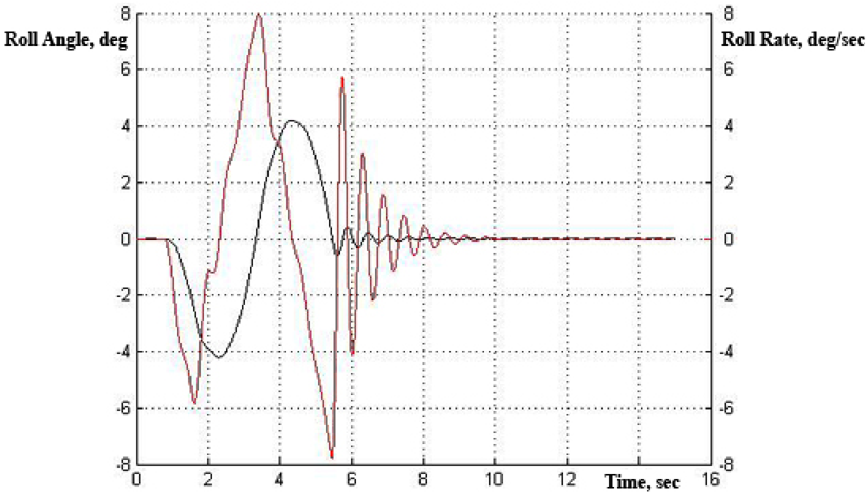

Figure 3: Roll angle (deg) and roll rate (deg/sec)

Analysis of results shows that maximal roll angles for such testing regime were 4.19 and 4.21 deg when the roll rate was 0.0482 and 0.0207 deg/sec at 4.35 and 2.32 sec. The roll rate reached maximum 8.00 and 7.94 deg/sec when roll angle was 0.0667 and 0.5541 deg at 5.56 and 3.41 sec.

Conclusion

The main goal of this paper is to describe the trends of developing of rollover prevention, analysis of ESC systems as one of the ways, rollover model is realized in MATLAB. Actually this paper and model are a basis of investigation into rollover prevention. For developed MATLAB rollover model in the future might be applied a rollover prevention control algorithms what will give possibility to perform tests without using any real vehicle and system. It will provide more effective investigates into rollover prevention and take less time for it.

Nomenclature

A_{ei} – effective square

a – lateral acceleration

a_l – accelerations of sprung mass

a_{tl} – accelerations of unsprung mass

c_t – tire stiffness

F – roll force

m_0 – sprung mass

p_a – atmospheric pressure

R – steering radius

U_{sg} – ratio of steering gear

V_1 – value in static position

V_i – value in a elastic element in the static position

z_l – displacement of sprung mass

z_{tl} – displacement of unsprung mass

$\frac{B_p}{B}$ – ratio

φ – roll angle

θ – steering angle

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