ROLLOVER AND LATERAL SLIDING STABILITY OF THREE WHEELED VEHICLES

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1. INTRODUCTION

Three Wheeled Vehicles (TWVs), with their higher manoeuvrability and low cost, offer an economical and convenient means of transport and are quite popular in Asian countries. However, a major drawback of such a vehicle is lack of stability due to absence of differential in its rear axle and high centre of gravity (CG). The instability in TWVs often leads to severe accidents and fatal injuries. This paper addresses two types of instabilities - Rollover and Lateral Sliding. The concept of Dynamic Stability Factor (*DSF*) for a four wheeled vehicle, defined and formulated by Jin et al [1], is modified for TWVs here, using a 3-degree of freedom (DOF) model. Stability boundaries for a TWV, with respect to various parameters viz., height of the centre of gravity (CG) from the ground, distance of the CG from the front axle, sprung mass, cornering stiffness of the tire and steering angle, are drawn. Further, sliding mode instability of the TWV is also investigated. A non-linear tire model is employed. Lateral sliding is analysed using Handling Diagrams. The limiting forward velocity for lateral sliding is found. Effect of terrain friction is also investigated.

2. VEHICLE AND TIRE MODELING

A 3-DOF mathematical model for TWVs is developed on the lines of the model used for a four wheeled vehicle by Jin et al [1]. Consider a vehicle moving with a constant forward speed U and a steering angle δ. The model has three degrees of freedom - the lateral velocity v, the yaw rate r and the roll motion ϕ (Figure 1). The body coordinate system Oxyz, is fixed at the CG of the vehicle model. The equations of motion in the lateral, yaw and roll direction can be established as

$$ma_y - m_s h\ddot{\phi} = F_f\cos\delta + 2F_r \quad (1)$$

$$I_z\dot{r} = aF_f\cos\delta - 2bF_r \quad (2)$$

$$I_x\ddot{\phi} - m_s h a_y = m_s g h\sin\phi - c\dot{\phi} - k\phi \quad (3)$$

where m, m_s, F_r, I_z, I_x, c and k are the mass, sprung mass, lateral force on rear tire, mass moment of inertia about z-axis, mass moment of inertia about x-axis, equivalent roll damping coefficient of the suspension and equivalent roll stiffness coefficient of the suspension, respectively.

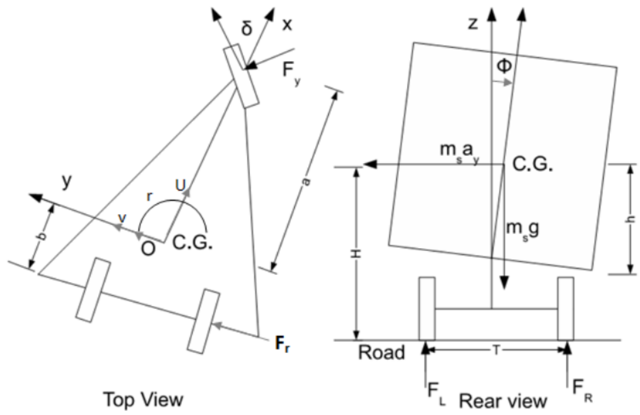

Figure 1: Top and Rear view of TWV

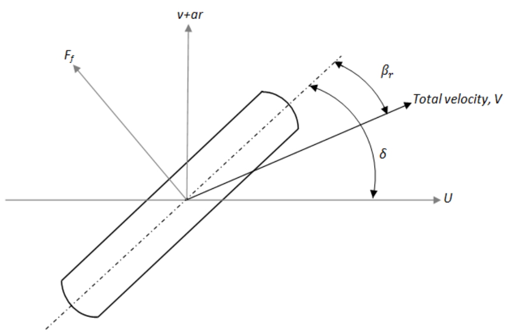

Figure 2: Top view of front tire.

3. DYNAMIC STABILITY FACTOR (*DSF*) FOR ROLLOVER PREDICTION

Jin et al [1] introduced the Dynamic Stability factor (*DSF*) for a four wheeled vehicle. A Dynamic Stability Factor (*DSF*) for a three wheeled vehicle is formulated using the 3-DOF model, on similar lines, which is used for rollover prediction. The steady state solution to the dynamic system is initially found out and then the condition for rollover is imposed to find the limiting value of lateral acceleration. Thus we get,

$$DSF = \frac{a_y}{g} = \frac{T}{2H} - \frac{2m_s h^2 U^2 k_f \cos\delta\,\delta k_r L}{(k - m_s g h)\left[2k_f k_r \cos\delta L^2 + mU^2 a k_f \cos\delta + 2mU^2 b k_r\right]H}$$

4. HANDLING DIAGRAMS FOR PREDICTION OF VEHICLE SLIDING

Handling diagram is the plot between lateral acceleration and the slip angle. The slope of this plot is indicative of the understeer, oversteer or neutral steer behaviour of the vehicle [2] - [4]. The slope of the handling diagram is termed as understeer coefficient (*K*). Lateral sliding of the vehicle is likely to occur when vehicle changes its steering response from oversteer condition to understeer condition or vice versa. The change in the sense of the slope of the handling diagram, from positive to negative or vice versa, can be considered that as the onset of sliding.

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5. SIMULATION RESULTS FOR ROLLOVER AND SLIDING MODE INSTABILITY

For steady state case with a steering angle of 10 degrees, the critical forward speed is found to be 10.3 m/s for the vehicle parameters as reported by Gawade et al [5]. Figure 4 shows the variation of lateral acceleration with time for the TWV at a forward velocity *U* of 10.4 m/s. It can be seen that *DSF* predicts rollover, while SSF does not. Figure 5 shows the comparison between *DSF* and SSF for various values of '*a*'. It can be readily seen that the SSF is independent of '*a*'. Similarly other parameters of TWV are also analyzed.

The non-linear Magic tire model is used [3] to study the sliding mode instability of the TWV. The response is numerically simulated and Handling Diagrams are constructed for prediction of vehicle sliding. It should be noted that Magic tire model incorporates the effect of terrain friction, μ, which is a major factor responsible for vehicle sliding. Handling Diagrams for various μ values are drawn and the limiting forward velocities of the TWV are obtained.

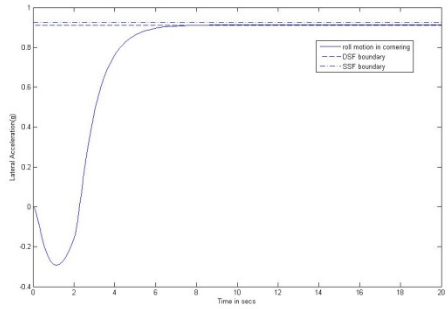

Figure 3: a_y (in *g*) vs. time (in seconds) at *U*=10.4 m/s

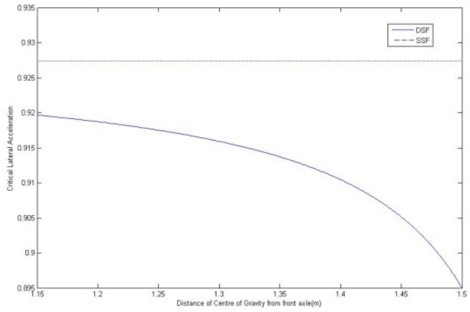

Figure 4: Critical a_y (in *g*) vs. '*a*'(in meters)

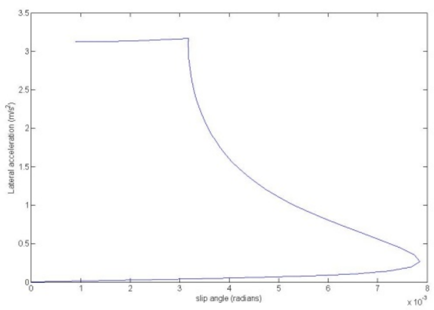

Figure 5: Handling diagram at μ=0.8 and *U*=6 m/s, a_y vs. slip angle

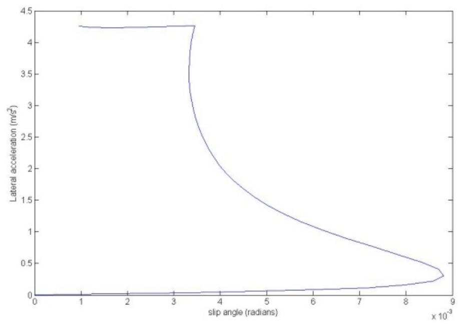

Figure 6: Handling diagram at μ=0.8 and *U*=7 m/s, a_y vs. slip angle

<u>Influence of terrain friction</u>

Figure 5 and 6 show the handling diagram for the vehicle at terrain friction coefficient of 0.8 at a forward velocity of 6 m/s and 7 m/s respectively. It is evident from the plot that the vehicle would slide laterally for a forward speed value somewhere in between 6 m/s and 7 m/s. Taking a conservative stand, we can consider limiting velocity (i.e. the maximum velocity below which the vehicle would not slide laterally) as 6 m/s. Similarly limiting forward velocites for lateral instability for other terrain friction values has been inferenced using Handling Diagrams.

CONCLUSION

A three degree of freedom TWV model is used for analyzing rollover and lateral sliding of TWV. The Dynamic Stability Factor (*DSF*) for a TWV is formulated and critical lateral acceleration and critical forward velocity are obtained. It is shown that *DSF* predicts vehicle rollover more accurately than Static Stability Factor (SSF) for a ramp step steering input. Influence of various parameters like the height of the CG from the ground level, distance of CG from the front axle, steering angle, track width, sprung mass of the vehicle, ratio of cornering stiffness of the front and rear tires and terrain friction on the vehicle rollover stability have been analyzed. Using Non-Linear Magic tire model, lateral sliding mode of instability of the TWV is also studied. It is observed that at lower terrain friction values the critical forward velocity (for vehicle lateral sliding) is much lower than that predicted for rollover.

References

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