Stability Analysis of A Motorcycle by Varying Castor Angle and Trail

Hardik R Sharma
PG Student
Department of Mechanical Engineering (ICE/ Auto)
L.D. College of Engineering

Dhruv U Panchal
Assistant Professor
Department of Mechanical Engineering
L.D. College of Engineering

Vikas Rai
PG Student
Department of Mechanical Engineering (ICE/ Auto)
L.D. College of Engineering

Ritesh Kumar Ranjan
PG Student
Department of Mechanical Engineering (ICE/ Auto)
L.D. College of Engineering

Bhavik B. Hirapara
PG Student
Department of Mechanical Engineering (ICE/ Auto)
L.D. College of Engineering

Abstract

The usage of two wheeler vehicles especially the motorcycles has increased by a big number in past couple of decades owing to their ease of riding and affordability. But when looking at the dynamics of the motorcycle they make up a complex dynamic system that requires a careful analysis to understand their working and behaviour in varied conditions. They are statically unstable and portray more complex behaviour dynamically. Many factors play role in governing the stability of the system, out of which the castor angle and trail play a pivotal role. The objective of the presented work is to analyse the intricate relation between castor angle and trail for the stability of the motorcycle under predefined running conditions. The present study focusses on typically used linearized differential equations of motion to study the behaviour of the motorcycle model by solving the equations under eigenvalue analysis and obtaining the eigenvalues for the system at different working speeds. Inferences are drawn from the obtained results regarding the stability of the motorcycle.
Keywords: Castor Angle, Dynamics, Eigenvalue Analysis, Stability, Trail

I. INTRODUCTION

The current work deals with the analysis of the effect of varying the castor angle and trail on the motorcycle. To carry out the analysis in mathematical terms a model is chosen and the equations of motion are obtained for the same. The equations of motion depict the relation of forces amongst the member involved in the system. These equations account for both translational as well as rotational motion. These are derived using either the Inertia principle or the Energy principle. The equations of motion used for the current work have been derived by employing the energy approach using Lagrangian methodology which involves the derivation of kinetic energy and potential energy of the system in consideration and by using the principle of virtual work derives the balancing forces involved.

II. MATHEMATICAL MODEL DESCRIPTION

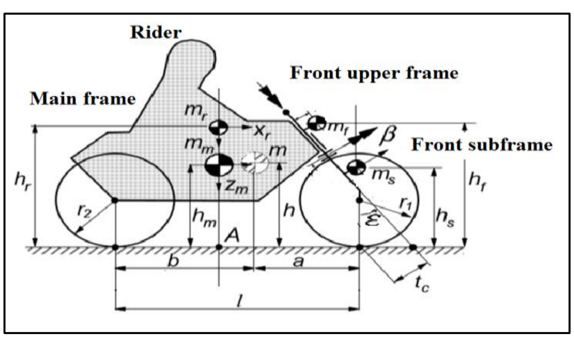

Fig. 1: Lumped Mass Model of the System Considered

The model consists of four bodies, namely, the rider, main frame (including rear wheel), front upper frame (steering head, rider weight), and front subframe (front forks, wheel). The figure highlights the various dimensions involved with bodies as per the SAE coordinate system convention.

- m_m = center of mass of main frame
- m_s = center of mass of subframe
- m_f =center of mass of front frame
- mr = center of mass of rider
- m = combined center of mass of the system
- h_m = height of center of mass of the main frame above the datum
- h_s = height of center of mass of the sub frame above the datum
- h_f = height of center of mass of the front frame above the datum
- h_r = height of center of mass of the rider above the datum
- h = height of combined center of mass of the system above the datum
- ß = is the front frame torsion angle
- ε = castor angle of the motorcycle
- t_c = normal trail

The equations of motion are derived using the following principle

$$\frac{d}{dt}\frac{\partial L}{\partial qi} - \frac{\partial L}{\partial qi} = Q_i \text{ , i=1,….,n}$$

where, q_i is the degree of freedom or the generalised coordinates
L is the lagrangian of the system (L = Kinetic Energy – Potential Energy)
Q_i is the generalised forces of the system
To carry out the analysis the range of castor angle is fixed from 15° to 30° and the values of trail are fixed from 70mm to 130mm. The model is run on speed ranging from 0 km/h to 100 km/h.

III. RESULTS

The eigenvalues are plotted against the forward velocity to analyse the systems behaviour. The following images show result being plotted against the forward velocity for the castor angle 15° and different values of trail varying from 70mm to 130mm set in steps of 10mm. The eigenvalues are plotted in two parts one being the imaginary part of the eigenvalues and the other is the real part of the eigenvalues against the forward velocity.

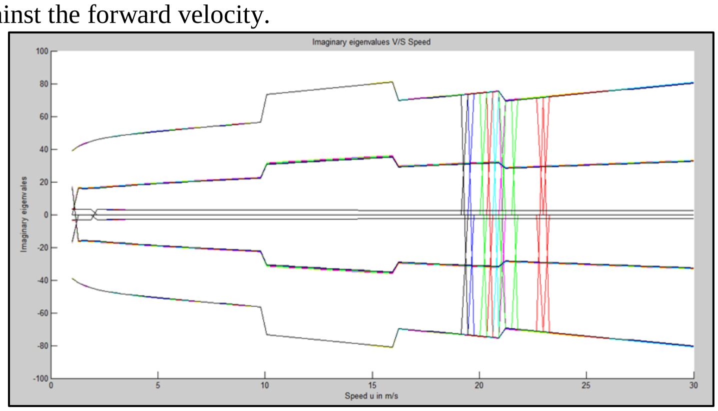

Fig. 2: Imaginary Part of the Eigenvalues Plotted Against the Forward Velocity

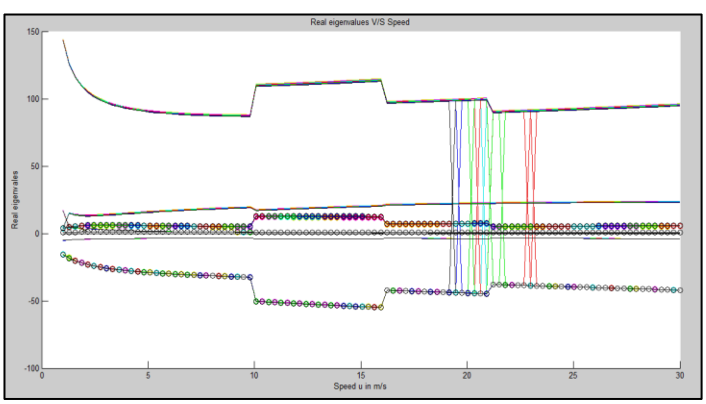

Fig. 3: Real Part of the Eigenvalues Plotted Against the Forward Velocity

The graphs of the eigenvalues against the velocity might seem uninteresting but they indicate the stability of the motorcycle when performing uncontrolled motion through the eigenvalues becoming zero and non-zero. The distinction in the results is made on the basis the stable points obtained on a particular value of trail. The broader is the speed range or higher is the number of points indicates a more stable system compared to others. Hence when driven in the particular range or at the particular speed the motorcycle can resist the perturbation and remain on track. The results indicate value of trail for every value of castor angle that is the most suitable in the used range. Thereby indicating how the system gets unstable with other value of trail being associated. Through the analysis it is also indicated the effect of varying these parameters on the inherent instabilities of the motorcycle namely, wobble, weave and capsize which are indicated by the eigenvalues when plotted against the forward velocity.

IV. CONCLUSION

After carrying out similar analysis for the castor angles ranging from 15° castor angle to 30° with the trail being varied from 70mm to 130mm various outcomes can be inferred. The analysis is then carried out in a simulation software bikeSIM to verify the obtained results from mathematical analysis. Results obtained show the effect of varying castor angles and trail on the stability of the motorcycle confirming the importance of the two parameters in the dynamic stability of the system. The results obtained are restricted to the particular chosen model as the change in location of mass centres, moment of inertia of the system, etc. also creates impact on the stability of the system.

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