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Review on Handling Characteristics of Road Vehicles

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ABSTRACT
Handling characteristics of vehicles are closely related to driving safety. Handling characteristics of road vehicles refer to its response to steering commands and to environmental inputs, such as wind gust and road disturbances that affect its direction of motion. Many traffic accidents are caused by undesired and unexpected handling behavior of vehicle. Hence it is necessary to understand the handling characteristics of vehicle. In this paper detail study is carried out related to handling characteristics of vehicles.

Keywords – Steady State Characteristics, Understeer Gradient, Constant Radius Test, Constant Speed Test, Transient response characteristics.

I. INTRODUCTION

Handling is a loosely used term meant to imply the responsiveness of a vehicle to driver input, or the ease of control. The cornering behavior of a motor vehicle is an important performance mode often equated with handling. As such, handling is an overall measure of the vehicle driver combination. The driver and vehicle is a "closed-loop" system meaning that the driver observes the vehicle direction or position, and corrects his/her input to achieve the desired motion. For purposes of characterizing only the vehicle, "open-loop" behavior is used. Open loop refers to vehicle response to specific steering inputs, and is more precisely defined as "directional response" behavior. The most commonly used measure of open-loop response is the understeer gradient. Understeer gradient is a measure of performance under steady state conditions, although the measure can be used to infer performance properties under conditions that are not quite steady-state (quasi steady-state conditions) [1]. The handling characteristics of a road vehicle refer to response to steering commands and to environmental inputs, such as wind gust and road disturbances that affects its direction of motion. There are two basic issues in vehicle handling: one is the control of the direction of motion of the vehicle; the other is its ability to stabilize its direction of motion against external disturbances. Handling characteristics of vehicles are related to vehicle active safety systems [2].

Forest fire patrolling vehicle is a kind of special vehicle that travels under off-road condition in forest. It should have better handling characteristics. Researcher has studied evaluate handling characteristics of a forest fire patrolling vehicle, two degrees of freedom mathematical and analytical model is built and steady state response characteristic is analyzed. Apart from the mathematical model, multi-body system dynamics model based on ADAMS software is built to compare with the mathematical model. Virtual experiments which include steady state turn and transient state response were simulated in order to analyze handling characteristics. The results showed that the results of mathematical method coincide with the results of virtual analysis method; the forest fire patrolling vehicle has understeering characteristics [3].

II. STEADY STATE HANDLING CHARACTERISTICS

Steady-state handling performance is concerned with the directional behavior of a vehicle during a turn under non time-varying conditions. An example of a steady-state turn is a vehicle negotiating a curve with constant radius at a constant forward speed [1]. Therefore, to obtain a desired set of steady-state equilibrium conditions of speed, steering-wheel angle and turning radius, it is possible to hold any one of them constant, vary the second and measure the third. The conditions that are to be held constant, varied and measured or calculated are summarized in Table No. 1 [5]

III. UNDERSTEER GRADIENT

The steady-state cornering equations are derived from the application of Newton's Second Law along with the equation describing the geometry in turns (modified by the slip angle conditions necessary on the tires). For purposes of analysis, it is convenient to represent the vehicle by the bicycle model shown in Figure 1 [1, 2].

For a vehicle traveling forward with a speed of *V*, the sum of the forces in the lateral direction from the tires must equal the mass times the centripetal acceleration.

$$\sum F_y = F_{yf} + F_{yr} = MV^2/R \qquad (1)$$

Also, for the vehicle to be in moment equilibrium about the center of gravity, the sum of the moments from the front and rear lateral forces must be zero.

$$F_{yf}\, b - F_{yr}\, c = 0 \qquad (2)$$

Table 1 Test Conditions

Test Method	Constant	Varied	Measured or Calculated
Constant Radius	Radius	Speed	Steering-wheel angle
Constant steering-wheel angle	Steering-wheel angle	Speed	Radius
Constant speed with discrete turn radii	Speed	Radius	Steering-wheel angle
Constant speed with discrete steering-wheel angles	Speed	Steering-wheel angle	Radius

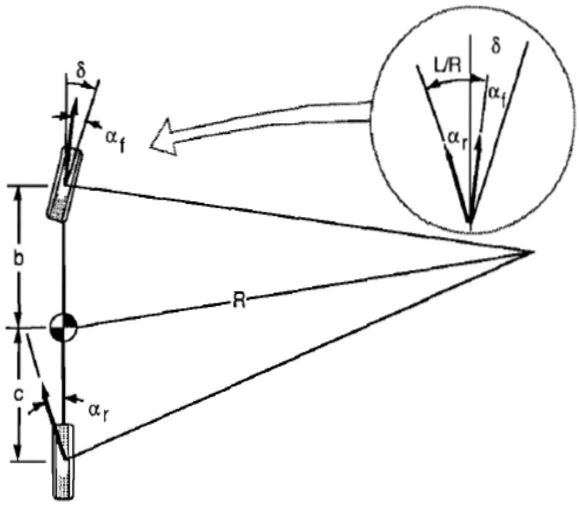

Fig.1 cornering of a bicycle model [1]

We must now look to the geometry of the vehicle in the tum to complete the analysis. With a little study of Fig. 1, it can be seen that:

$$\delta = 57.3\frac{L}{R} + \left(\frac{W_f}{C_{\alpha f}} - \frac{W_r}{C_{\alpha r}}\right)\frac{V^2}{gR} \qquad (3)$$

Where:
δ = Steer angle at the front wheels (deg)
L = Wheelbase (m)
R = Radius of turn (m)
V = Forward speed (m/sec)
g = Gravitational acceleration constant = 9.8 m/s^2
W_f = Load on the front axle (Kg)
W_r = Load on the rear axle (Kg)
$C_{\alpha f}$ = Cornering stiffness of the front tires (N/deg)
$C_{\alpha r}$= Cornering stiffness of the rear tires (N/deg)
b = Distance of front axle from C.G. of the vehicle
c = Distance of rear axle from C.G. of the vehicle
F_{yf} = Lateral (cornering) force at the front axle (N)
F_{yr} = Lateral (cornering) force at the rear axle (N)
M = Mass of the vehicle (Kg)
α_f = Front Wheel Slip Angle (deg)
α_r = Rear Wheel Slip Angle (deg)

The equation is often written in a shorthand form as follows:

$$\delta = 57.3\, {}^{L}/_{R} + K a_y \qquad (4)$$

where:
K = Understeer gradient (deg/g)
a_y= Lateral acceleration (g)

Equation (3) is very important to the turning response properties of a motor vehicle. It describes how the steer angle of the vehicle must be changed with the radius of turn, *R*, or the lateral acceleration V^2/gR. The term $\left[\frac{W_f}{C_{\alpha f}} - \frac{W_r}{C_{\alpha r}}\right]$determines the magnitude and direction of the steering inputs required. It consists of two terms, each of which is the ratio of the load on the axle (front or rear) to the cornering stiffness of the tires on the axle. It is called the "Understeer Gradient," and will be denoted by the symbol, K, which has the units of degrees/g.

IV. TESTING OF STEADY STATE HANDLING CHARACTERISTICS

To measure the handling behavior of a road vehicle under steady-state conditions, various types of test can be conducted on a skid pad, which in essence is a large, flat, paved area. Two types of test can be distinguished the constant radius test and the constant forward speed test [1, 2, 5].

During the tests, the steer angle, forward speed, and yaw velocity (or lateral acceleration) of the vehicle are usually measured. Yaw velocity can be measured by a rate-gyro or determined by the lateral acceleration divided by vehicle forward speed.

Lateral acceleration can be measured by an accelerometer or determined by the yaw velocity multiplied by vehicle forward speed. Based on the relationship between the steer angle and the lateral acceleration or yaw velocity obtained from tests, the handling characteristics of the vehicle can be evaluated.

4.1 Constant Radius Test

Understeer can be measured by operating the vehicle around a constant radius turn and observing steering angle versus lateral acceleration. The method closely replicates vehicle operation in many highway situations, such as the constant radius turns in off ramps from limited access highways. At a minimum, instrumentation must be available to measure steering wheel angle and lateral acceleration. Given the radius of turn and some measure of vehicle velocity (from the speedometer, fifth wheel or by lap time), lateral acceleration can be computed using the relationship:

$$a_y = V^2/Rg \tag{5}$$

The recommended procedure is to drive the vehicle around the circle at very low speed, for which the lateral acceleration is negligible, and note the steer angle (Ackerman steer angle) required to maintain the turn. (The experimenter is challenged to develop good technique for this process as cross slope on the test surface, bumps, etc., will cause the vehicle to drift in and out as it proceeds, complicating the determination of the average steer angle.) Vehicle speed is then increased in steps that will produce lateral accelerations at reasonable increments (typically 0.1 g), noting the steer angle at each speed. The steer angle (divided by the steering ratio to obtain the road wheel angle) is then plotted as a function of lateral acceleration as illustrated in Figure 2.

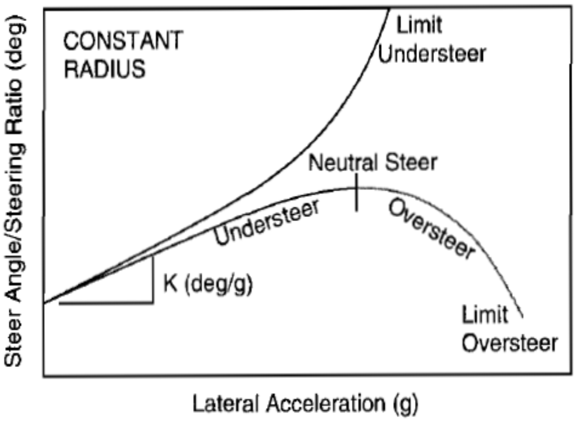

Fig. 2 Example measurements of understeer gradient by constant radius method [1]

The meaning of this plot can be seen by taking the derivative of Eq. (4):

$$\frac{\partial \delta}{\partial a_y} = \frac{\partial}{\partial a_y}\left(57.3\frac{L}{R}\right) + K\frac{\partial a_y}{\partial a_y} \tag{6}$$

Since the radius of turn is constant, the Ackerman steer angle is also constant and its derivative is zero. Thus:

$$K = \frac{\partial \delta}{\partial a_y} \tag{7}$$

The slope of the steer angle curve is the understeer gradient. A positive slope (upward to the right) indicates understeer, zero slopes are neutral steer, and a negative slope is oversteer. Typical measurements will take one of the forms shown in Figure 2. Some vehicles will be understeer over the entire operating range, remaining so to the limit. Others may be understeer at low lateral acceleration levels but change to oversteer at high lateral acceleration levels and exhibit limit oversteer.

4.2 Constant Radius Test

Understeer can be measured at constant speed by varying the steer angle. Measurements by this method closely duplicate many real driving situations since vehicles are normally driven at near constant speed. With this method the radius of turn will vary continuously requiring more extensive data collection to determine the gradient. In addition to measuring speed and steer angle, the radius of turn must be determined for each condition as well. The most practical means to measure radius of turn is either by measuring lateral acceleration or yaw rate. The radius of turn is derived from the measurements using the appropriate form of the relationships below:

$$R = \frac{V^2}{a_y} = \frac{V}{r} \tag{8}$$

V = Forward speed (m/s)

a_y = Lateral acceleration (*m/sec*^{2})

r = Yaw rate (radians/sec)

The Ackerman steer angle gradient for this test procedure is obtained by substituting Eq. 8 into Eq. 4, eliminating the radius. This produces the form:

$$\delta = 57.3\frac{L}{R} + Ka_y = 57.3L\frac{a_y}{V^2} + Ka_y \tag{9}$$

Again taking derivatives with respect to lateral acceleration, we obtain the expression for the understeer gradient:

$$K = \frac{\partial \delta}{\partial a_y} - \frac{\partial}{\partial a_y}\left(57.3\frac{L}{V^2}\right) \tag{10}$$

Since speed and wheelbase are constant, the Ackerman steer angle gradient (the second term on the right-hand side) is a straight line of constant slope and appears in a data plot as shown in Figure 3. The Ackerman steer angle gradient is neutral steer. In regions where the steer angle gradient is greater than that of the Ackerman, the vehicle is understeer. A point where the two have the same slope is neutral steer, and where the steer angle gradient is less than the Ackerman, the vehicle is oversteer. For the oversteer vehicle, the point where the slope of the steer angle curve is zero is the stability boundary corresponding to the critical speed.

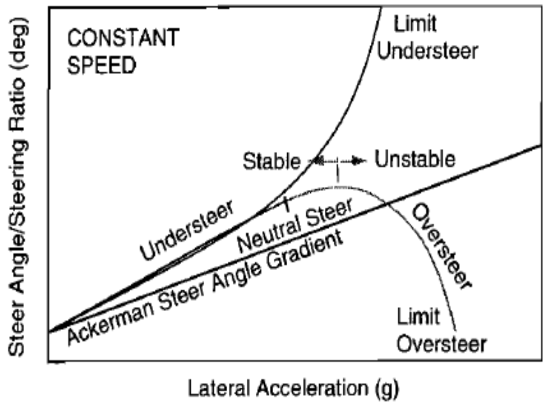

Fig. 3 Example measurements of under steer gradient by constant speed method [1]

V. TRANSIENT RESPONSE CHARACTERISTICS

Between the application of steering input and the attainment of steady-state motion, the vehicle is in a transient state. The behavior of the vehicle in this period is usually referred to as "transient response characteristics." The overall handling quality of a vehicle depends, to a great extent, on its transient behavior. The optimum transient response of a vehicle is that which has the fastest response with a minimum of oscillation in the process of approaching the steady-state motion. In analyzing the transient response, the inertia properties of the vehicle must be taken into consideration. During a turning maneuver, the vehicle is in translation as well as in rotation. To describe its motion, it is convenient to use a set of axes fixed to and moving with the vehicle body because, with respect to these axes, the mass moments of inertia of the vehicle are constant, whereas with respect to axes fixed to earth, the mass moments of inertia vary as the vehicle changes its position [2, 4].

5.1 Step Input Test Procedure

The step-steer test is carried out to determine the sensitivity of the vehicle response to a sudden change in steering input. More specifically, it measures how promptly the vehicle reacts to a steering input and how quickly it can settle to a new equilibrium. Drive the vehicle at test speed in a straight line. The Initial speed shall not deviate by more than 2 km/hr from test speed. Starting from a 0^o/s ± 0.5^o/s yaw velocity equilibrium condition, apply a steering input as rapidly as possible to a preselected value and maintain at that value for several seconds after the measured vehicle motion variables have reached steady state. In order to keep steering input short relative to vehicle response time, time between 10% and 90% of steering input should not be greater than 0.15 sec. No change in throttle position shall be made, although speed may decrease. A steering wheel stop may be used for selecting the input angle. Take data for both left and right turns. All data shall be taken in one direction followed by all data in the other direction. Alternatively, take data successively in each direction for each acceleration level from lowest to highest level. Data shall be taken throughout desired range of steering inputs and response variable outputs. Determine the steering wheel angle amplitude by steady state driving on a circle the radius of which gives the preselected steady state lateral acceleration at required test speed. The standard steady-state lateral acceleration level is 4 m/s^2. Additional levels of 2 & 6 m/s^2 may be used. Perform all test runs at least 3 times [6].

The following performance evaluation specifications are extracted from the raw data:

- response times for lateral acceleration and yaw rate
- peak response times for lateral acceleration and yaw rate
- overshoot for lateral acceleration and yaw rate

VI. MULTI BODY VEHICLE MODEL

The vehicle dynamic model can be built with the help of ADAMS Software. Firstly the templates are built up, then the subsystems are built based on the templates, and the whole vehicle is finally assembled. The model includes the following subsystems such as Front & rear suspensions, Steering subsystem, Body subsystem, Power train subsystem, Braking subsystem and Tire subsystem [7].

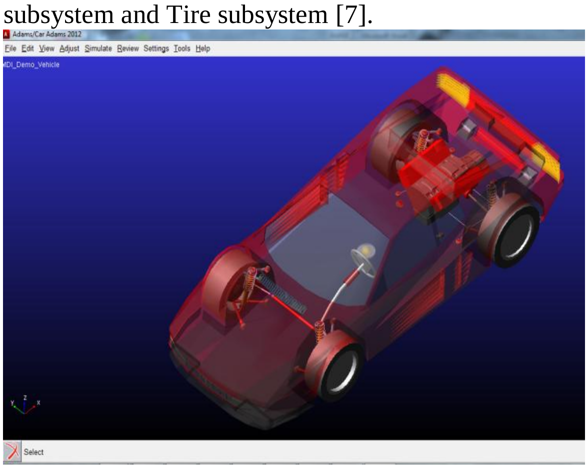

Fig. 4 the Demo Vehicle in ADAMS [8]

ADAMS/Car software we can perform steady state and transient response test under simulation tab the full vehicle analysis then open-loop steering events and cornering events. There are in built roads are provided so we can perform different types of testing [8].

VII. CONCLUSION

In this paper handling characteristics of road vehicles have been studied. For that cornering behavior of vehicle is analyzed and constant radius test and constant speed test is discussed. These can be used to quantify term “understeer gradient”. Selection of proper mathematical model is also important so that we can predict its behavior analytically in transient response test methods. ADAMS software can be used to create virtual multibody dynamics model and perform steady state cornering and transient response tests.

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